United States
Department of
Agriculture
Forest Service
Pacific Northwest
Research Station

Research Paper
PNW-RP-485
November 1995

Extended Rotations and Culmination Age of Coast Douglas-fir: Old Studies Speak to Current Issues

Robert O. Curtis

Author

ROBERT O. CURTIS is a principal mensurationist, Forestry Sciences Laboratory, 3925 93d Ave., S.W., Olympia, WA 98512-9193

Abstract

Curtis, Robert O. 1995. Extended rotations and culmination age of coast Douglas-fir: old studies speak to current issues. Res. Pap. PNW-RP-485. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 49 p.

Trends of mean annual increment and periodic annual increment were examined in 17 long-term thinning studies in coast Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco) in western Washington, western Oregon, and British Columbia. Maximum ages included ranged from about 90 years on high sites to 117 years on a low site. None of the stands had clearly reached culmination of mean annual increment, although some appeared close; periodic annual increments declined only slowly. Extended rotations combined with increased thinning harvests are promising components of any strategy to reduce conflicts between timber production and other forest values. These comparisons indicate that rotations can be considerably extended without reducing long-term timber production. A major problem in such a strategy is design of thinning regimes that can maintain some reasonable level of timber flow during any transition period.

Keywords: Growth and yield, mean annual increment, rotation, Douglas-fir, *Pseudotsuga menziesii*, alternative silviculture, ecosystem management.

Summary

Trends of mean annual increment and periodic annual increment were examined in 17 long-term thinning studies in Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco) in western Washington, western Oregon, and British Columbia. Maximum ages were about 90 years on high sites to 117 years on a low site. Problems in evaluating growth trends and culmination ages are discussed. None of the stands had clearly reached culmination of mean annual increment, although some seemed close. Periodic annual increments declined only slowly. Culmination has not yet been observed in systematically thinned stands that are relatively free from damage. The observed trends seem generally consistent with some other recent comparisons. Extended rotations combined with increased use of thinning are promising components of any strategy to reduce conflicts between timber production and other forest values. These comparisons indicate that rotations can be considerably extended without reducing long-term timber production; value production probably would increase. A major problem in such a strategy is design of thinning regimes that can maintain a reasonable level of timber flow during the transition period while producing stand conditions compatible with other management objectives. Several examples of drastic thinnings seem promising. The continuing value of long-term permanent plot studies is emphasized.

Contents

Introduction

Extended rotations—whether applied on the basis of the large even-aged units used in the recent past, or to small even-aged patches of a few acres—have been proposed as a component of strategies for mitigating current conflicts among forest uses and reconciling amenity, wildlife, and environmental values with timber production (Curtis 1994a, Curtis and Marshall 1993, Newton and Cole 1987, Weigand and others 1994).

Two key questions involved in such proposals are those of (1) the effects of extended rotations on short-term timber supply and (2) the effects on long-term timber production. Extending rotations would reduce short-term timber flow during the transition period, although reductions could be offset to some unknown degree by increased production from thinnings and reduced pressures to remove land from the timber base. The probable effects of extending rotations on long-term timber production are not generally recognized. Coast Douglas-fir (*Pseudotsuga menziesii* var. *menzieseii* (Mirb.) Franco) is a very long-lived species that maintains growth to advanced ages, and there is reason to believe that—compared with the relatively short rotations adopted by many owners—moderate increases in rotation age would substantially increase long-term timber production.

Several approaches to the question of probable long-term effects are possible. Curtis (1992a) showed that a bias exists in the long-used yield tables of McArdle and others (1961); incorporation of modern height curves changes the shape of the yield curves and indicates culmination at substantially greater ages than those given in the earlier publication.

Curtis (1994b) compares estimates for selected management regimes produced by a number of widely used stand simulators. Although there are considerable differences among simulators, results indicate culmination ages considerably greater than the 40- to 50-year rotations now common in many ownerships, and suggest little change in production rates for an undetermined but considerable number of years beyond culmination.

This report presents additional evidence from examination of actual growth trends observed in existing long-term thinning studies.

In the period from about 1930 to 1960, a considerable number of thinning studies were established in the Pacific Northwest by foresters who were then thinking in terms of relatively long rotations and who saw commercial thinning as a major future activity. But, conversion of old stands was found to be a much more profitable activity than thinning; and with the move toward shortened rotations many owners lost interest in commercial thinning. Recent reductions in timber supply and improved markets for small material, coupled with pressures to reduce the use of clearcutting, have revived interest in commercial thinning. Data from many of these old studies are still available, and some of the installations still exist. Much of the data have never been adequately analyzed or reported.

This report examines trends of mean annual increment and periodic annual increment in long-term thinning studies and discusses their implications for management.

Objectives

The study objective was to examine the historical record of stand development on a series of long-term thinning studies for indications of:

- age of culmination
- shape of MAI and PAI curves
- effects of management regime and site differences on MAI and PAI curves
- consistency of patterns among installations
- consistency with estimates from other sources

A secondary objective was to locate, assemble, and edit basic data from long-term thinning studies for use in the Stand Management Cooperative modeling project (not reported here).

Methods

Definitions

Mean annual net increment (MAInet) is cumulative net volume production (live stand + thinnings), divided by years required to produce it; that is, average production rate from stand establishment to a given year.

Periodic annual net increment (PAInet) is change in cumulative net production between two successive stand measurements, divided by number of years in the period. It approximates current annual increment (CAI), the annual growth occurring in any given year. Gross periodic annual increment (PAIgross) also includes mortality between the two successive measurements, and it thus is a measure of biological production as opposed to usable volume.

The curves of MAI and PAI in volume or value over stand age have characteristic shapes (fig. 1). The maximum point ("culmination") of the MAI curve identifies the age at which average production per year is maximized. This is also the point at which the PAI curve intersects the MAI curve.

Data Assembly

Data were assembled from records of long-term experimental installations that included some type of systematic thinning or spacing treatment on relatively large plots and for which repeated tagged tree remeasurements of reasonable precision were available. Location of suitable installations was based on personal knowledge, past data inventories of the Stand Management Cooperative and the earlier DFSIM modeling effort (Curtis and others 1981), and inquiry to various landowners and research organizations.

Data sources consisted in part of past and current experiments of the Pacific Northwest Research Station. Weyerhaeuser Co., Port Blakely Tree Farms, British Columbia Ministry of Forests, and Oregon State University also contributed proprietary data and access to their installations. Several installations lacking recent measurements were remeasured in 1991 and 1992.

Data Summarization

Data quality differed widely; some data required rather arbitrary adjustments to resolve inconsistencies in successive measurements of diameters and heights.

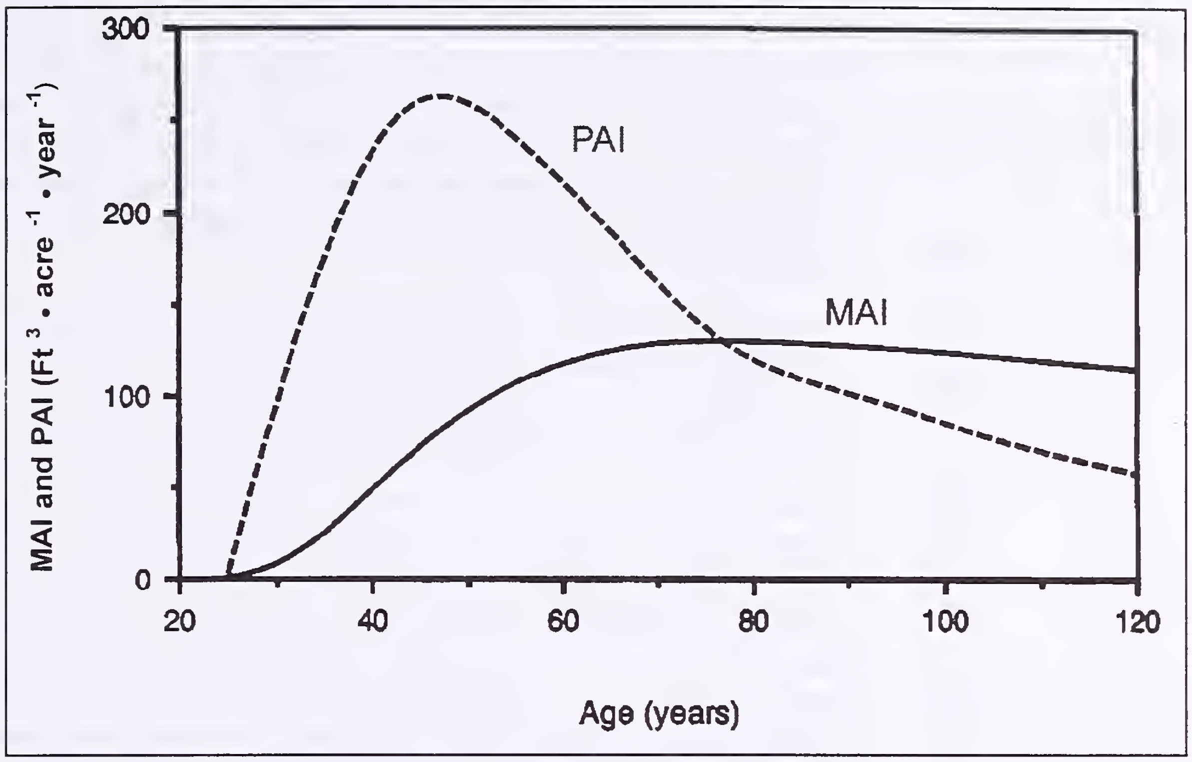

Figure 1—Mean annual net increment (MAI) and periodic annual net increment (PAI) curves for well-stocked unmanaged stands. Values for site III are from table 2 in McArdle and others (1961), adjusted to a 6-inch merchantable top.

Height-diameter curves were initially fit with a modification of Hyink and others' (1988) constrained height curve fitting procedure. This worked well for data with consistently high-quality height measurements but often gave erratic results for data containing poorly distributed height samples or major inconsistencies in consecutive height measurements, or that required interpolation across large gaps in the age distribution of the height sample.

Most of the data were subsequently resummarized by using height-diameter curves smoothed over age (Curtis 1967). In most cases the form,

$$H = 4.5 + \exp(a + b/Age + c/D^{**}n + e/D^{**}n/Age) ,$$

where $0.5 =< n =< 1.5$, was found satisfactory.

Differences between PAI estimates for individual growth periods obtained by the two methods were sometimes large, but overall trends usually differed little and the differences do not alter inferences.

All volumes were expressed as merchantable cubic volume inside bark to a 6-inch top (CV6) of trees 7.6 inches and larger in diameter; a value that more closely approximates usable volume than does the total stem volume often used in research studies. (Differences are small except for very young or very dense stands or very poor sites.) Calculations were based on the Bruce and DeMars (1974) equation for total stem volume, and conversion to CV6 through tarif system equations (Brackett 1973).

Data Analysis

Many of the early studies were unreplicated, and definitions of planned treatment were often vague or unavailable. Although some installations were designed studies with replication, there was no consistency in design or treatment definitions among installations. Consequently no simple overall averaging or statistical analysis was possible. Ultimately, the data will be incorporated in the database used to develop response surfaces for the simulation model now under development by the Stand Management Cooperative.

The data are treated here as a series of case histories, in which inferences are based on graphic comparisons of MAI and PAI curves and their apparent consistency among installations. Although much other information is present in the data, no attempt was made at general comparisons of other aspects of stand development.

Individual graphs of MAInet, PAInet, PAIgross over age and RD over age were prepared for each plot (RD = basal area/sqrt(QMD), where QMD is quadratic mean diameter; Curtis 1982). RD is a measure of relative stand density, and its trend over time describes one aspect of a thinning regime; a value of RD70 approximates "normal" or full stocking, as shown in normal yield tables. The number of such graphs was far too large for publication, and in this report, plot data from replicated studies have been averaged within treatments. Data also have been averaged within treatment groups where treatments seemed similar in nature and results.

Results

The principal characteristics and results are summarized in the appendix for each of the 17 installations examined, with figures showing trends of RD, MAI, and PAI for each installation and treatment or treatment group.

The overall result is that none of the stands examined have clearly reached culmination age, in the absence of major stand damage. We have as yet no examples of culmination in systematically thinned stands, although some appear near culmination.

Table 1 gives condensed information on the range in ages and sites represented, and on average diameters and dominant heights at the most recent measurement by treatment or treatment group. (There were often considerable differences in initial conditions and treatments among plots combined into groups, and one should not attempt to infer treatment effects from these values; they are intended only as a rough description of the range in conditions included.)

Table 1—Installations included in analyses; also see appendix

Installation	Age span	Stand origin	Site index[a]	Treatment[b]	QMD last measurement[c]	Number, last measurement	D40, last measurement[d]	H40, last measurement[e]
	Years				*Inches*	*Per acre*	*Inches*	*Feet*
Fuller Hill	41-71	Natural	I	NT	21.2	128	26.7	168
				T-1	22.6	96	27.0	172
				T-2	20.2	147	24.7	171
				T-3	21.9	116	26.5	173
Hoskins LOGS	20-50	Natural	I	NT	12.0	377	17.6	123
				T-1	22.0	52	22.8	122
				T-3	18.8	100	21.2	124
				T-5	16.7	153	20.4	127
				T-7	15.9	207	19.6	125
Delezenne	36-71	Natural	I–	T-1	23.1	63	25.2	163
				T-2	20.2	111	24.2	167
				T-3	24.2	56	26.1	162
XT-1	47-90	Natural	II+	NT	20.3	125	26.2	168
				T-1	24.0	71	26.8	167
XT-2	48-88	Natural	I	NT	21.6	119	26.4	173
				T-1	27.3	56	29.6	178
XT-3	39-77	Natural	I–	NT	24.5	84	28.7	165
				T-1	25.2	59	29.0	168
XT-7	42-76	Natural	II+	NT	21.8	125	27.6	168
				T-1	26.0	49	27.2	155
				T-2	25.5	60	28.7	159
				T-3	23.7	61	30.1	167
McCleary	57-90	Natural	I– to II+	NT	23.2	132	30.3	183
				Th	26.3	81	32.7	178
Schenstrom	31-76	Natural	II–	NT	13.5	315	19.3	142
				Th	19.0	101	22.5	142
Snow Creek	26-63	Planted	II+	NT	12.6	236	16.7	118
			II–	T-1	16.3	121	20.0	127
Black Rock (plots 27 29, 30, 31)	47-80	Natural	III+	NT	15.8	227	22.2	140
			II	T-1	19.4	125	24.8	149
			III	T-2	18.4	107	24.2	125
			II+	NT	28.5	51	29.9	160
Voight Creek	38-70	Natural	II–	NT	14.0	270	20.7	135
				Th	15.9	168	22.4	141
Wind River	23-68	Planted	III–	10x10	11.7	323	16.5	114
				12x12	12.7	239	16.9	116

Table 1—Installations included in analyses; also see appendix (continued)

Installation	Age span	Stand origin	Site index[a]	Treatment[b]	QMD last measurement[c]	Number, last measurement	D40, last measurement[d]	H40, last measurement[e]
	Years				*Inches*	*Per acre*	*Inches*	*Feet*
Stampede LOGS	33-58	Natural	III	NT	10.7	378	16.5	110
				T-1	17.1	62	18.1	109
				T-3	15.7	95	17.6	109
				T-5	14.5	138	18.6	113
				T-7	13.1	192	17.0	114
Martha Creek	19-73	Natural	III	NT	11.6	349	18.1	121
				T-8x8	11.8	328	17.6	120
				T-2	12.6	275	18.1	116
Lookout Mt.	27-81	Natural	IV+	NT	13.2	264	18.6	114
	31-81	Natural	III	T-1	16.3	174	21.1	132
Mount Walker	64-117	Natural	IV+	NT	14.7	279	23.0	137
				T-1	17.0	148	24.0	129
				T-2	16.2	202	22.4	137

[a] King 1966.
[b] NT = unthinned, T-n = thinning treatment or treatment group n.
[c] QMD = quadratic mean diameter, all species combined.
[c] D40 = average diameter of largest 40 trees per acre.
[e] H40 = average height of largest 40 trees per acre.

Discussion

Problems in PAI Estimation

Estimation of PAI curves is neither easy nor precise. PAI estimates are greatly dependent on accurate estimates of periodic height increment. Unfortunately, available height measurements are often inaccurate and sampling has often been inadequate and inconsistent. The crucial importance of good height estimates in growth studies is often not realized until the analysis stage is reached. Summarization techniques must account for change in height-diameter and volume-diameter relationships with advancing age. The constrained fitting and smoothing techniques used here reduced the problems but did not eliminate them.

Mortality is inherently highly variable from period to period and introduces large fluctuations in PAInet. A further complication is that many records were unclear or inconsistent in recording salvaged mortality, and the convention used was often unspecified; in some cases salvaged mortality was apparently included in volume removed in thinning, in others it was excluded. In most cases, the effect of such inconsistencies on trends was slight.

The very short measurement periods (1 or 2 years) used in some studies accentuate the effects of measurement errors and short-term fluctuations in real growth in producing erratic fluctuations in estimates. The problem was reduced by combining short measurement periods into periods 3 to 5 years in length.

In some instances combining short growth periods and differences in merchantable size limits and in methods of estimating heights produce MAI and PAI curves that differ from previously published information for the same installations. Although such differences are sometimes noticeable for individual growth periods, they do not materially alter general trends and do not affect conclusions.

Frequent wide fluctuations in estimated growth for successive periods represent a combination of estimation errors and real differences. The Martha Creek and Mount Walker installations in particular show sharp declines in increment—apparently associated with weather-related stand damage—that were interpreted at the time as indicating approach to culmination, but which were followed by recovery in subsequent years. The fact that the PAI curve approaches the MAI curve at the most recent measurement date does not guarantee that they will not diverge widely at the next measurement. One cannot be certain that culmination has been reached until one has gone well past it.

Despite uncertainties in estimates for individual growth periods, the general nature of trends over time seems clear.

Possible Sampling Biases

Experiments that involve initial subjective selection of plot locations are always open to the objection that plots were chosen to avoid the irregularities in stocking, differences in species composition, and existing damage that characterize the real world of the manager. Such objections are probably less valid for very long-term experiments such as those discussed here, which usually undergo various degrees of unanticipated disruption.

The McCleary and Voight Creek studies were not only large in area and of relatively long duration but also used systematic sampling and are therefore free from such criticisms. However, the plots used in Miller's superimposed study (appendix) were presumably a subset selected to avoid such problems. Means of all plots do indicate a lower PAI curve than do means of Miller's four plots per treatment at McCleary; but the two are virtually identical for Voight Creek where Miller included a much larger number of thinned plots.

Data Limitations

The data included few plantations, few stands with early respacing, and no stands established with genetically improved stock; hence, they may not be completely comparable in early development to stands regenerated in the recent past. But, those plantations and respaced stands that are included show trends comparable to the other stands, and the initial measurement data suggest that many of the naturally regenerated and initially unmanaged stands had relatively low initial stocking and may not have been greatly different from the managed stands of more recent years. The Hoskins levels-of-growing-stock (LOGS) and Stampede Creek LOGS installations in particular, though of natural origin, were homogeneous in initial condition and have differed little in development from several planted stands in the LOGS series that were not included here. It seems reasonable to accept the trends shown as indicative of those to be expected in the future for reasonably homogeneous even-aged stands that have not suffered severe damage.

The long-term effects on these trends of genetically selected stock, intensive site preparation, and alternative possible fertilization regimes are largely speculative. We have no examples available of the effect of fertilization applied over the life of a stand; analogy with site effects suggests that this might lead to earlier culmination. On the other hand, it has been shown experimentally (Miller and Webster 1979) that fertilization toward the end of the rotation tends to delay culmination.

General Trends

As expected, thinning produced substantial gains in average diameters compared to no thinning. These gains represent both the effect of removal of small trees and accelerated growth on the remaining trees. Gains are much more striking in those installations in which thinning began at an early age. Any overall differences in cubic volume yield between thinned and unthinned were often obscured by small site differences and differences in initial stocking among plots and treatments and were not self-evident. Results appeared consistent with the expectation, based on other work, that the principal benefits of commercial thinning are not increased cubic volume production in early life but (1) increased average tree size and value per unit of volume, (2) probable increased long-term production on longer rotations, (3) improved stand resistance to wind and snow damage, and (4) provision of timber supply under constraints that require managers to minimize the visual impacts of forestry operations and provide favorable wildlife habitat.

The observed MAI and PAI trends are generally consistent with the simulation results of Curtis (1994b) and with MAI curves derived from McArdle's normal yield table (Curtis 1992a). The data do not extend, however, to the advanced ages at which large differences among simulators appear (which are themselves extrapolations), and a number of installations include extreme thinning treatments that are of particular interest and outside the range discussed by Curtis.

Mean annual increment has not clearly culminated in any of the installations examined. No thinning study in the region has been continued for a sufficiently long time and to a sufficiently advanced age to determine when culmination will occur in stands with systematic stocking control.

The observed trends suggest that, as expected, culmination will occur at a younger age on good sites than on poor sites, and a number of the high site installations do appear to be close to culmination. In contrast, the installation on the poorest site (Mount Walker) is still increasing in MAI at age 117.

Gross PAI curves do not appear markedly different for unthinned and conservatively thinned stands. In many cases these are nearly horizontal or only slowly declining. Those unthinned stands that have attained near-limiting relative densities, however, frequently show sharp reductions in net PAI associated with competition-related mortality (ex: Hoskins, Martha Creek plots 14 and 18); many stands appear to be entering this phase near the end of the range of ages included. In many conservatively thinned stands and unthinned stands of moderate density, both gross and net PAI trends seem to be nearly horizontal or only slowly declining, in marked contrast to the net PAI pattern for well-stocked natural stands depicted in figure 1. (The rapid decline in net PAI in figure 1 probably reflects both the known bias in the normal yield table [Curtis 1992a] and acceleration of suppression-related mortality with increasing age in heavily stocked stands.)

Several installations are of particular interest, both because they represent particularly strong data sets and because they show interesting behavioral characteristics.

Hoskins and Stampede Creek LOGS—The nine installations of the regional cooperative LOGS study follow a common design (Curtis and Marshall 1986). Even though relatively young compared to the other studies discussed, they are of special interest because they represent tightly controlled and sharply contrasting density regimes, with thinning begun early, and with unusually precise, high-quality measurements. The Hoskins (site I) and Stampede Creek (site III) installations are two of the most advanced installations in the series and have now reached what some have regarded as reasonable rotation ages. Results (appendix, figs. 3B and 15B) show clearly that all thinning treatments are still far from culmination, and there is as yet no indication as to when this may occur. Final harvest at their present ages (50 and 58 years) would mean major losses in production relative to their potential.

In contrast, the Hoskins unthinned plots have reached very high densities followed by heavy mortality; the associated decline in PAInet may or may not indicate approaching culmination.

Development of the other seven installations in the series, not included in this report, seems to be following similar patterns.

Voight Creek—Voight Creek and the contemporaneous McCleary study were two largescale commercial thinning experiments in mid-age natural stands. The plots that Miller continued as part of a superimposed fertilizer study provide the longest sequence of measurements. These included only four plots each for the Voight Creek unthinned condition, and for thinned and unthinned conditions at McCleary. The following discussion refers to the records for 14 plots that are available for the three thinning treatments at Voight Creek and extend to age 70 (appendix fig. 13C). Trends for the other four-plot samples appear more or less similar but are less well defined.

After a low at about age 45, soon after the beginning of the experiment, PAI steadily increased over the period of observation and was still far above MAI and had not clearly begun to decline by age 70. The stand was cut shortly afterward. This is a somewhat unusual and unexpected pattern. One can hypothesize several factors that may be involved:

- The stands suffered heavy damage in the 1955 freeze, followed by some windfall and snowbreakage in 1958 and 1960 (Reukema 1972).
- Thinnings were conducted as a commercial operation in a period when small material was of very marginal value. Consequently a considerable number of the larger and faster growing trees were cut, a practice that would not be recommended or necessary today. Although thinnings were not particularly heavy in terms of basal area or volume removed, the removal of large vigorous trees would be expected to cause some loss in growth and delay in response to thinning.
- Possible climatic effects (discussed below).

Taken together, these may be a partial explanation for the low PAI during the early part of the observation period.

Black Rock—Collectively, this set of 42 large (mostly 1-acre) plots represents the most extensive trial of contrasting thinnings at one location in the region. Measurements extend from the mid-1950s to the present (approximate stand age 80 at most recent measurement), albeit with serious gaps in height information. The data are now being updated and edited under a cooperative agreement between Oregon State University and the Pacific Northwest Research Station, but most were not available in time for inclusion in this report. The data are in any case too extensive to be adequately presented in the format used here, and a future Oregon State University publication is planned.

Data for four plots are included; plot 27, unthinned, site III; plot 29, "light" thinning, site II; plot 30, "heavy thinning," site III; and plot 31, "heavy crop tree thinning," site II+. These were selected because they form a group of nearby plots that are often shown to visitors and are probably representative. The striking feature of all these is that MAI was still increasing at age 80, with nearly constant PAI (appendix, fig. 12.)

Very Heavy Thinning

The XT-7 and Schenstrom installations and Black Rock plots 31 and 30 represent instances where density was reduced to very low levels, either by a single very heavy thinning or by a series of lighter thinnings, followed by an extended recovery period during which PAI increased or remained constant. PAI was nearly constant over recent measurement periods and still well above MAI. (See appendix, figs. 8, 10 and 12.) These very heavy thinnings have (1) provided relatively high intermediate volume yield, (2) produced visually attractive stands, and (3) depressed PAI for a limited period, followed by rapid growth that has continued to the present. No unusual mortality has occurred. Culmination age is still at some unknown point in the future.

This rapid growth is taking place on a relatively small number of large trees and must therefore be accompanied by large gains in quality and value, although these have not been evaluated.

Possible Climatic Effects

It is well known that year-to-year differences in growth exist, associated with weather. Work in the dry climate areas of the interior west has shown pronounced differences in periodic growth related to climatic fluctuations, primarily in rainfall. Similar effects have been shown for mid-and high-elevation forests in the Pacific Northwest (Henderson and Brubaker 1986), although they have not been clearly demonstrated for low-elevation forests west of the Cascade Range in the Pacific Northwest. This does not mean that they do not exist.

Summer rainfall records in the Olympia area show a relative low from about 1956 to 1966 and a relative high from about 1967 to 1986, followed by reduced rainfall in 1987 and subsequent years. If this represents regional trends and is in fact reflected in growth, it could be a contributing factor in the somewhat peculiar PAI trend at Voight Creek, and in the prolonged rapid growth at advanced ages seen in many of these installations.

This is speculation, and present interpretations are made on the assumption that climatic changes can be ignored.

Culmination Ages, Rotations, and the National Forest Management Act

The possible advantages of extended rotations (combined with increased use of commercial thinning) include:

- Reduced land area in regeneration and early development stages, hence
  - reduced visual impacts

  - lower annual regeneration costs
  - less need for herbicides, slash burning, and so forth
- Larger trees and higher quality wood
- Improved habitat for some wildlife species
- Hydrological and long-term site productivity benefits
- Increased carbon storage associated with larger growing stock
- Opportunity to adjust present unbalanced age distributions toward a regulated forest
- Preservation of flexibility to allow
  - adaptation to unknown future social, economic, technological, and political changes
  - correction of errors stemming from incomplete biological knowledge

Even-aged management with extended rotations is well adapted to the biological characteristics of our major tree species and requires little new knowledge of regeneration and stand management practices beyond that already available. Extended rotations combined with increased use of thinning (and, perhaps, use of regeneration areas considerably smaller than in the recent past, concurrently with thinning in the adjacent stand) are promising means of providing the amenity, wildlife, and other values desired by the public. This would reduce the visual (and political) impacts of forestry operations and help to defuse current controversies while maintaining long-term timber production. The examples discussed demonstrate that this would not necessarily reduce long-term volume growth from present levels and might even increase long-term value production.

The economic and biological aspects of rotation length have been argued for at least a century and a half, and arguments still continue. The traditional economic argument leads to the rotation that maximizes the discounted value of all future costs and returns (the rotation of "soil rent"), which is usually shorter than that which maximizes volume MAI. In its most common and simplistic form, this ignores or inadequately accounts for wildlife, water, fish, and amenity values (which usually do not accrue to the landowner); and it does not recognize the facts that an owner is not completely free to adopt a form of management that ignores nontimber values, that public policy considerations demand "sustainability," and that public perceptions increasingly impinge on a landowner's freedom of action through regulation and through pressure for land withdrawals for special uses. It also often ignores or inadequately accounts for the fact that longer rotations (combined with thinning) can be expected to produce stands with higher values per cubic foot, because of (1) the higher value of large trees, and (2) the gains in quality obtainable from selection of leave trees in thinning.

These factors are real and cannot be excluded from the rotation decision even though their expression in monetary terms may be highly imprecise or impossible. Nontimber values and public perceptions have become the dominant influences on management of Forest Service and some other public lands, and their political and regulatory consequences involve large costs that cannot be ignored by any owner.

The National Forest Management Act of 1976 (NFMA) specified that rotations on National Forest lands shall approximate culmination age. This implicitly assumed that MAI patterns and age of culmination are fixed and well-understood characteristics of a species and ignored the fact that culmination age is itself influenced by the management regime applied.

A minimum age that attains 95 percent of merchantable cubic volume yield at culmination has been interpreted as meeting the requirement. Any rotation age between the minimum and maximum ages producing 95 percent of maximum could also be considered to meet the NFMA requirement. Neither of these points is well defined, but a broad range obviously exists within which rotations can be determined by other considerations.

Compared to the relatively short rotations now used by many non-Federal owners, moderate extension of rotations would increase both volume and value of timber produced. But rotations are influenced by financial and supply constraints and owner objectives as well as by biology, and the rotation of maximum mean annual volume increment is probably not appropriate for many non-Federal owners. It does seem clear, however, that continuation of the recent trend toward very short rotations on many non-Federal lands can only mean sharply reduced productivity relative to potential, restriction of future management options, and exacerbation of antiforestry attitudes among the general public.

The Timber Supply Problem

The biggest practical problem in implementing extended rotations is the need to maintain some reasonable level of timber harvest during any transition period. This need cannot be ignored by public owners and is a critical consideration for others. How much can potentially be produced from thinnings? What are the most appropriate thinning regimes?

The examples of XT-7, Schenstrom, and Black Rock 31 suggest that thinning regimes can be designed that combine high levels of intermediate yield and relatively infrequent entries with development of stands acceptable from the standpoints of both timber and nontimber values.

There is a need for further evaluation of existing information bearing on this question and for large-scale trials that include radical thinning regimes and provide for accurate and detailed long-term measurement of results. Associated with this is the need for better evaluation of the effects of management on timber quality and value.

In Conclusion

These comparisons once again illustrate the great value of high-quality long-term permanent plot experiments. Most of our knowledge of stand development and quantitative silviculture comes from such studies, including much information on questions unthought of at the time of study establishment. The potential knowledge gains from re-examination of existing data and surviving old permanent plot installations are far from exhausted. We owe a great debt to the far-sighted pioneers who began these studies and to those who persevered in maintaining them despite the vagaries of funding, personnel changes, and administrative attitudes and policies over the years.

Metric Equivalents

1 inch = 2.54 centimeters

1 foot = 0.3048 meter

1 square foot = 0.09290 square meter

1 cubic foot = 0.02832 cubic meter

1 acre = 0.40469 hectare

1 square foot per acre = 0.22957 square meter per hectare

1 cubic foot per acre = 0.06997 cubic meter per hectare

RD in English units = 6.944*RD in metric units

Literature Cited

Brackett, Michael. 1973. Notes on tarif tree volume computation. Resour. Manage. Rep. 24. Olympia, WA: Washington Department of Natural Resources. 26 p.

Bruce, David; DeMars, Donald J. 1974. Volume equations for second-growth Douglas-fir. Res. Note PNW-239. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 5 p.

Curtis, Robert O. 1967. Height-diameter and height-diameter-age equations for second-growth Douglas-fir. Forest Science. 13(4): 367-375.

Curtis, Robert O. 1982. A simple index of stand density for Douglas-fir. Forest Science 28(1): 92-94.

Curtis, Robert O. 1992a. A new look at an old question—Douglas-fir culmination age. Western Journal of Applied Forestry. 7(4): 97-99.

Curtis, Robert O. 1992b. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 11—Stampede Creek: a 20-year progress report. Res. Pap. PNW-RP-442. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 47 p.

Curtis, Robert O. 1994a. Rotations, public perceptions, and yields. In: Weigand, J.F.; Haynes, R.W.; Mikowski, J.L., eds. High quality forestry workshop: the idea of long rotations; 1993 May 10-12; Silver Falls, OR. Spec. Pap. (SP) 15. Seattle, WA: Center for International Trade in Forest Products, University of Washington: 62-73..

Curtis, Robert O. 1994b. Some simulation estimates of mean annual increment of Douglas-fir: results, limitations, implications for management. Res. Pap. PNW-RP-471. Portland, OR: U.S. Department of Agriculture, Forest Service. Pacific Northwest Research Station. 27 p.

Curtis, Robert O.; Clendenen, Gary W.; DeMars, Donald J. 1981. A new stand simulator for coast Douglas-fir: DFSIM users guide. Gen. Tech. Rep. PNW-128. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 79 p.

Curtis, Robert O.; Marshall, David D. 1986. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 8—the LOGS study: twenty-year results. Res. Pap. PNW-356. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 113 p.

Curtis, Robert O.; Marshall, David D. 1993. Douglas-fir rotations—time for reappraisal? Western Journal of Applied Forestry. 8(3): 81-85.

Henderson, Jan; Brubaker, Linda. 1986. Responses of Douglas-fir to long-term variations in precipitation and temperature in western Washington. In: Oliver, C.D.; Hanley, D.P.; Johnson, J.A., eds. Douglas-fir: stand management for the future. Contrib. 55. Seattle, WA: College of Forest Resources, University of Washington, Institute of Forest Resources: 162-167.

Hyink, D.M.; Scott, W.; Leon, R.M. 1988. Some important aspects in the development of a managed stand growth model for western hemlock. In: Ek, A.R.; Shifley, S.R.; Burk, T.E., eds. Forest growth modelling and prediction: Proceedings of IUFRO conference; 1987 August 23-27; Minneapolis, MN. Gen. Tech. Rep. NC-120. Minneapolis, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 9-21.

King, James E. 1966. Site index curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser For. Pap. 8. Centralia, WA: Weyerhaeuser Forestry Research Centre. 49 p.

Marshall, David D.; Bell, John T.; Tappeiner, John C. 1992. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 10—the Hoskins study, 1963-83. Res. Pap. PNW-RP-448. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 65 p.

McArdle, R.E.; Meyer, W.H.; Bruce, D. 1961. The yield of Douglas-fir in the Pacific Northwest. Tech. Bull. 201. [Washington, DC]: U.S. Department of Agriculture. 72 p.

Meyer, Walter H. 1931. Thinning experiments in young Douglas-fir. Journal of Agricultural Research. 43(6): 537-546.

Miller, Richard E.; Reukema, Donald L.; Williamson, Richard L. 1979. Response to fertilization in thinned and unthinned Douglas-fir stands. In: Gessel, S.P.; Kenady, R.M.; Atkinson, W.A., eds. Proceedings, forest fertilization conference; 1979 Sept 25-27; Union, WA. Contrib. 40. Seattle, WA: University of Washington, College of Forest Resources, Institute of Forest Resources: 150-157.

Miller, Richard E.: Webster, Steve R. 1979. Fertilizer response in mature stands of Douglas-fir. In: Gessel, S.P.; Kenady, R.M.; Atkinson, W.A., eds. Proceedings, forest fertilization conference; 1979 Sept. 25-27; Union, WA. Contrib. 40. Seattle, WA: University of Washington College of Forest Resources, Institute of Forest Resources: 126-132.

Newton, M.; Cole, E.C. 1987. A sustained-yield scheme for old-growth Douglas-fir. Western Journal of Applied Forestry. 2(1): 22-25.

O'Hara, Kevin L. 1988. Stand structure and growing space efficiency following thinning in an even-aged Douglas-fir stand. Canadian Journal of Forest Research. 18: 859-866.

O'Hara, Kevin L. 1990. Twenty-eight years of thinning at several intensities in a high-site Douglas-fir stand in western Washington. Western Journal of Applied Forestry. 5(2): 37-40.

Reukema, Donald L. 1972. Twenty-one-year development of Douglas-fir stands repeatedly thinned at varying intervals. Res. Pap. PNW-141. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 23 p.

Reukema, Donald L. 1979. Fifty-year development of Douglas-fir stands planted at various spacings. Res. Pap. PNW-253. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 21 p.

Reukema, Donald L.; Pienaar, Leon V. 1973. Yields with and without repeated commercial thinning in a high-site-quality Douglas-fir stand. Res. Pap. PNW-155. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 15 p.

U.S. Laws, Statues, etc.; Public Law 94-588. National Forest Management Act of 1976. Act of Oct. 22, 1976. 16 U.S.C. 1600(1976).

Warrack, G.C. 1967. E.P. 62-66, 204-5, 283—thinning experiments in Douglas-fir. In: British Columbia Forest Service research review, year ended March 1967. Victoria, BC: British Columbia Forest Service: 81-82.

Warrack, G.C. 1979. Successive thinnings in a natural stand of Douglas-fir over a fifty-year period. Res. Note 87. Victoria, BC: Research Branch, Ministry of Forests. 11 p.

Weigand, J.F.; Haynes, R.W.; Mikowski, J.L., eds. 1994. High quality forestry workshop: the idea of long rotations; 1993 May 10-12; Silver Falls, OR. Spec. Pap. (SP) 15. Seattle, WA: Center for International Trade in Forest Products, University of Washington. 242 p.

Worthington, Norman P. 1961. Some observations on yield and early thinning in a Douglas-fir plantation. Journal of Forestry. 59.(5): 331-334.

Worthington, Norman P. 1966. Response to thinning 60-year-old Douglas-fir. Res. Note PNW-35. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 5 p.

Appendix

This section summarizes the principal characteristics and results of each installation. Emphasis is on the general nature of MAI and PAI trends, and much supplementary information on stand statistics and details of study designs and differences among plots and among thinnings has been omitted. Installations are listed in rough order of site quality, from highest to lowest. Site class is based on King (1966). Within installations, treatments that appeared generally similar in RD trends and results have been combined for plotting purposes.

Fuller Hill

Location—T.17N., R.6W. (southwest Washington, near Elma) .

Site class—I+.

Stand origin—Natural.

Design—A split-plot design with three thinning treatments and control randomly assigned to twelve 1/2-acre main plots, with one 1/4-acre fertilized subplot within each main plot. Results shown are for the unfertilized subplots only.

Treatments—Three thinning treatments and control.

History—The present experiment, superimposed on some older untreated plots, was established in 1961 (age 41). Two thinnings were made, the first at age 41 and the second at age 53. Was last remeasured at age 72.

Published documentation—None.

Results—RD, MAI, and PAI trends are shown in figure 2. Unthinned plots appear near culmination, primarily because of sharply increasing density-related mortality. Trends on thinned plots suggest possible approach to culmination although it had not been reached at age 72.

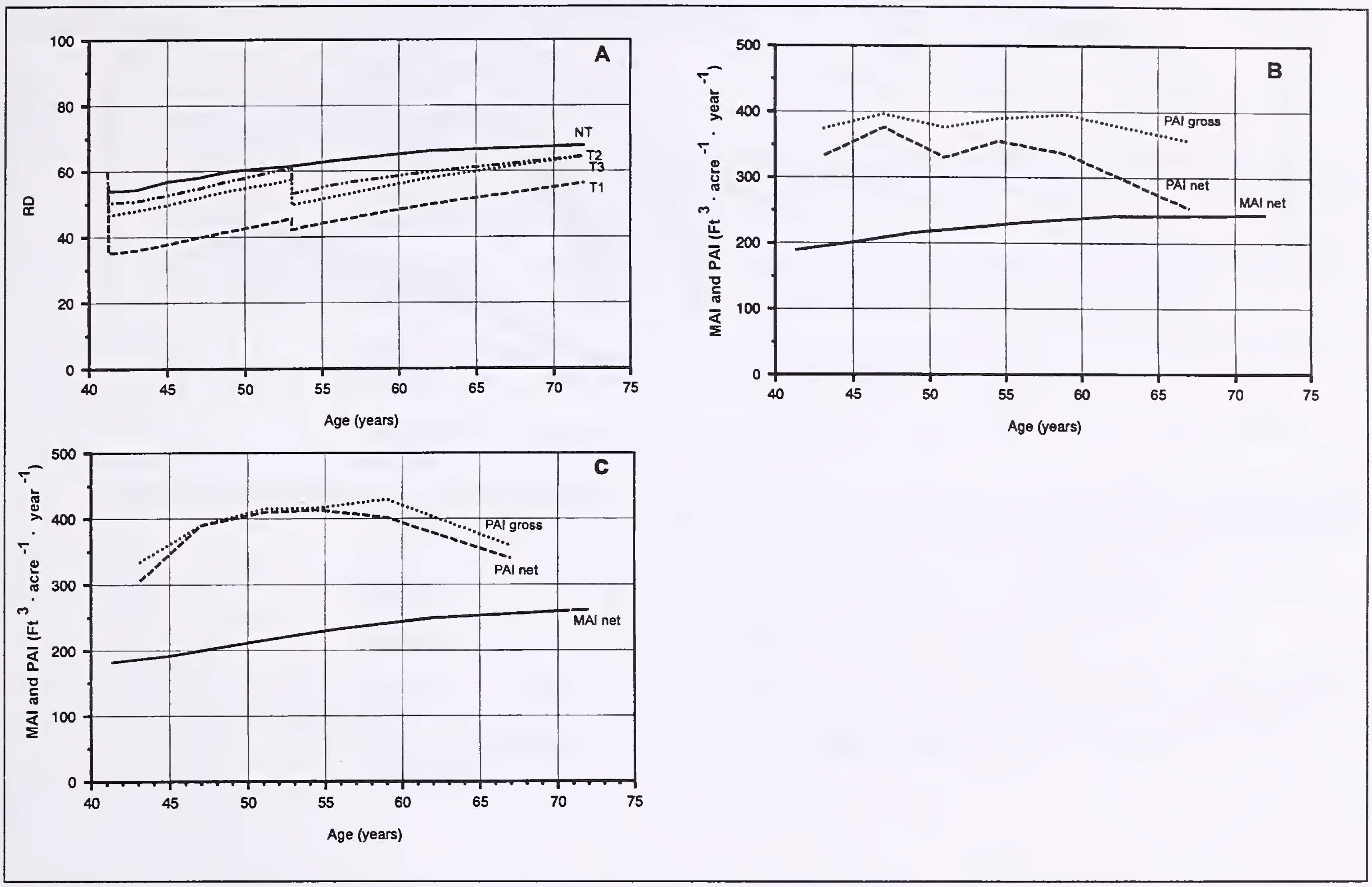

Figure 2—Fuller Hill: (A) mean relative density (RD) trends for unthinned and thinning treatments 1, 2, and 3; and mean MAI and PAI trends for (B) unthinned and for (C) thinning treatments 1, 2, and 3 combined.

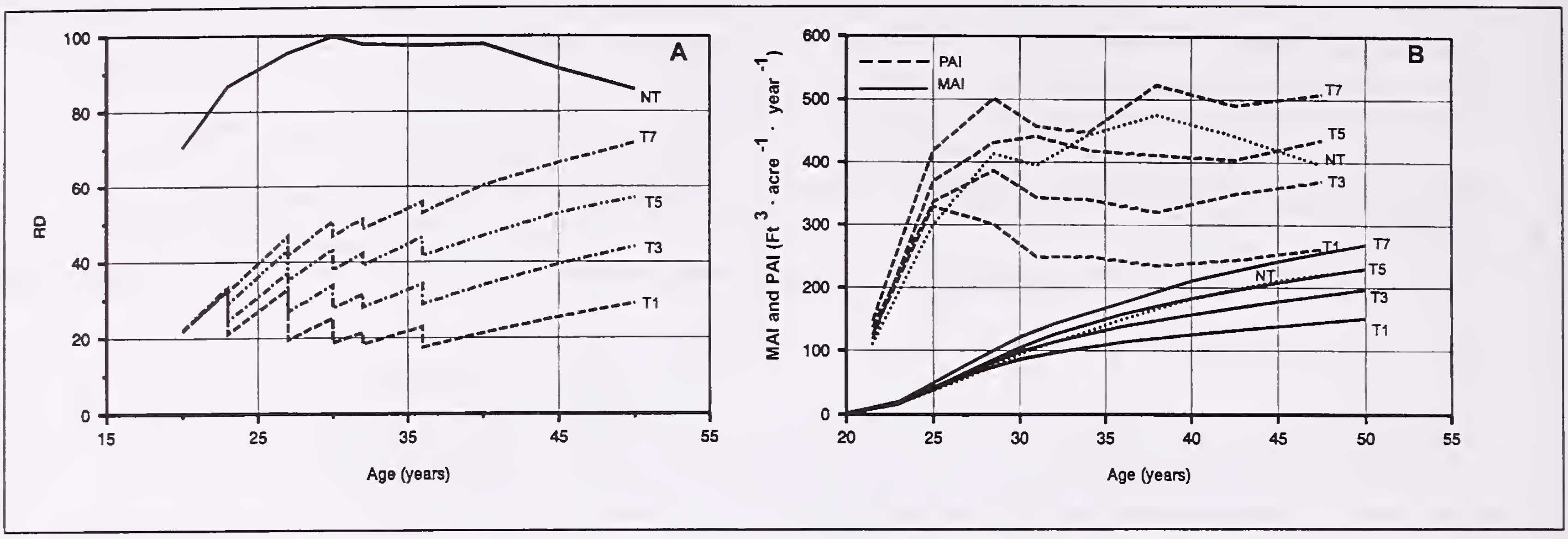

Figure 3—Hoskins LOGS, thinning treatments 1, 3, 5, and 7 and control: (A) relative density (RD) trends, and (B) mean MAInet and PAInet trends.

Hoskins LOGS

Location—T.10S., R.7W. (Oregon Coast Range, near Hoskins) .

Site class—I–.

Stand origin—Natural.

Design—Standard levels-of-growing stock (LOGS) cooperative study design. Twenty-seven 1/5-acre plots, completely randomized, three replicates each of eight thinning treatments and control.

Treatments—Standard LOGS thinning treatments, defined in terms of percentage of gross basal area growth on the control retained in each thinning treatment.

History—Established in 1963 at age 20. Thinned five times at intervals of 10 feet of height growth. Most recent measurement in 1993 at age 50.

Published documentation—Marshall and others (1992) and prior reports listed therein.

Results—Trends are shown for treatments 1, 3, 5, and 7 (10, 30, 50, and 70 percent of periodic gross basal area growth of control retained) and control only. By ages 30-40, the control had attained an extremely high and evidently unstable RD, followed by a sharp decline associated with rapidly increasing density-related mortality (fig. 3). Mortality was negligible on thinned plots and is not shown.

MAInet and PAInet curves show that, to age 50, PAI of thinned plots is still far above MAI; these are obviously far from culmination. The PAInet curve for the unthinned plots is declining because of recent mortality, which could indicate approach to culmination.

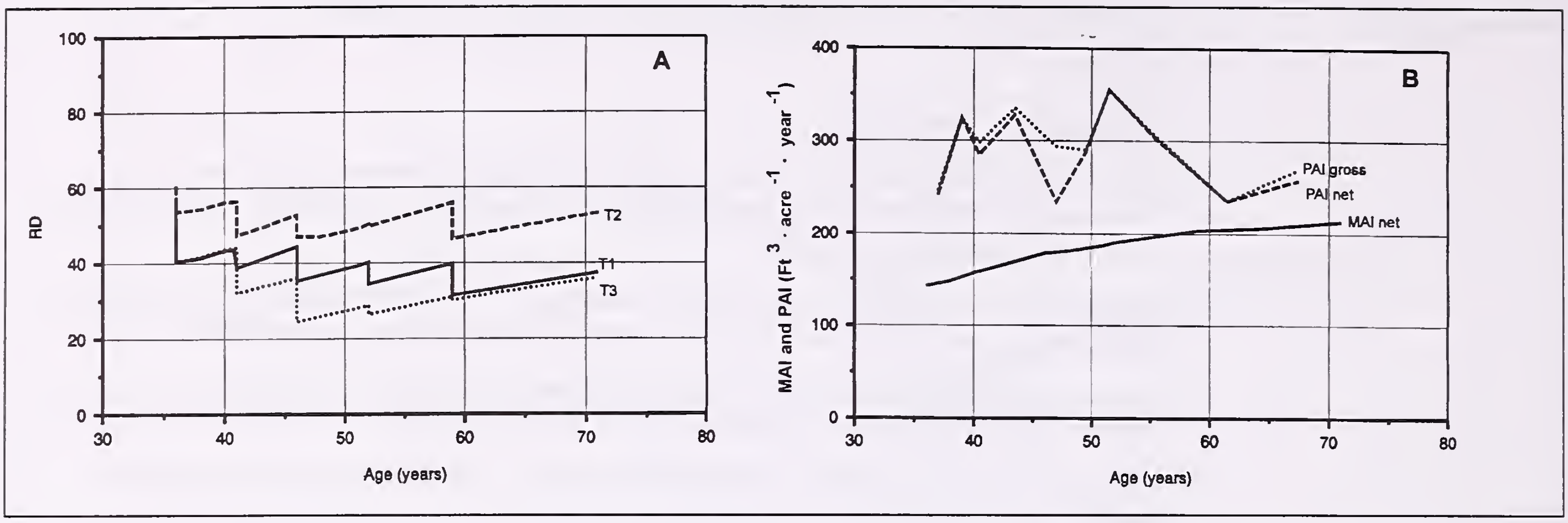

Figure 4—Delezenne: (A) mean relative density (RD) trends for thinning treatments 1 (constant basal area), 2 (increasing basal area), and 3 (decreasing-increasing basal area); and (B) MAI and PAI trends for means of treatments 1, 2, and 3.

Delezenne

Location—T.17N., R.6W. (southwest Washington, near Elma).

Site class—I–.

Stand origin—Natural.

Design—Twelve 1/2-acre plots. Each treatment was assigned to a pair of adjacent plots, so the design actually consists of six 1-acre plots subdivided for recordkeeping purposes into 1/2-acre subplots.

Treatments—Treatments were designated as constant, increasing, and decreasing-increasing basal area sequences, but there were considerable differences among plots within a treatment. No fully comparable control available.

History—Established in spring 1957 at total age 36. Thinned 1957, 1962, 1967, 1973, and 1980. Remeasured at approximate 5-year intervals to age 71. Two plots destroyed by logging in 1984.

Published documentation—O'Hara (1988, 1990).

Results—Figure 4 shows RD trends over time as means of plots within each of the three treatment groups, and mean MAI and PAI trends. Culmination has not been reached at age 71, but trends suggest that it will probably occur by about age 75-80.

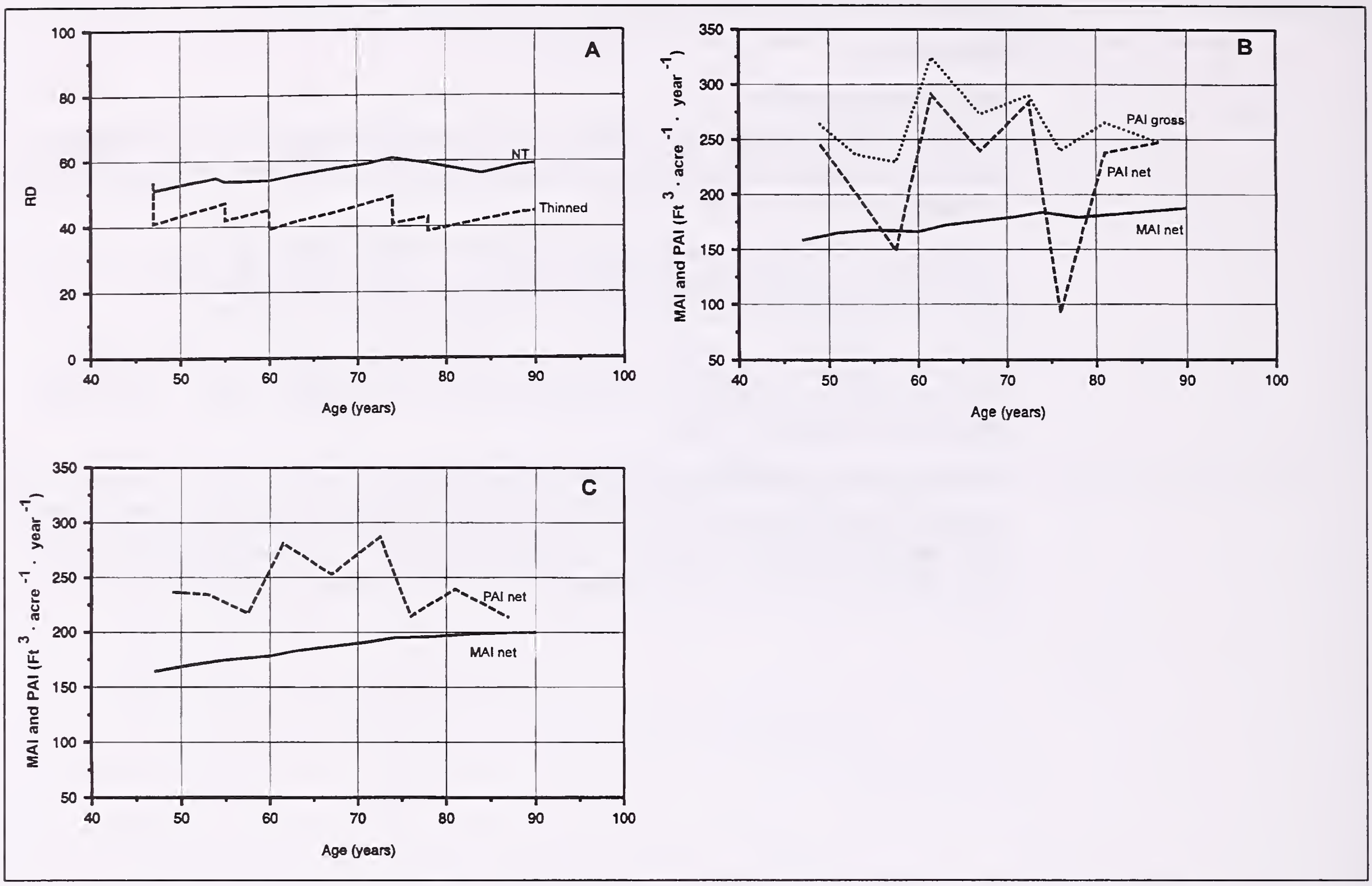

Figure 5—Port Blakely XT-1: (A) relative density (RD) trends for thinned and unthinned treatments; and MAI and PAI trends for (B) unthinned and (C) thinned treatments.

Port Blakely XT-1

Location—T.18N., R.5W. (southwest Washington, near McCleary).

Site class—II+ .

Stand origin—Natural.

Design—Two 10-acre contiguous treatment areas, one thinned and one control. Each sampled by five systematically located 1/5-acre plots.

Treatments—Thinned vs. unthinned. The original stand appears to have been relatively widely spaced, as shown by the presence of only 200-250 trees per acre at age 47. Thinnings were frequent and light with no sharp reductions in stocking.

History—Established in 1948 at age 47. Frequent repeated light cuts on thinned area. Last measured in 1991 at age 90.

Published documentation—None.

Results—Trends are shown in figure 5. (No mortality recorded on the thinned area; presumably, it was salvaged and included in thinning volume.)

PAInet on the control is erratic and one cannot judge whether or not culmination in net volume has been reached; however, PAIgross is still well above MAI. The thinned stand has not culminated by age 90 although the PAI and MAI curves are converging and culmination appears likely soon.

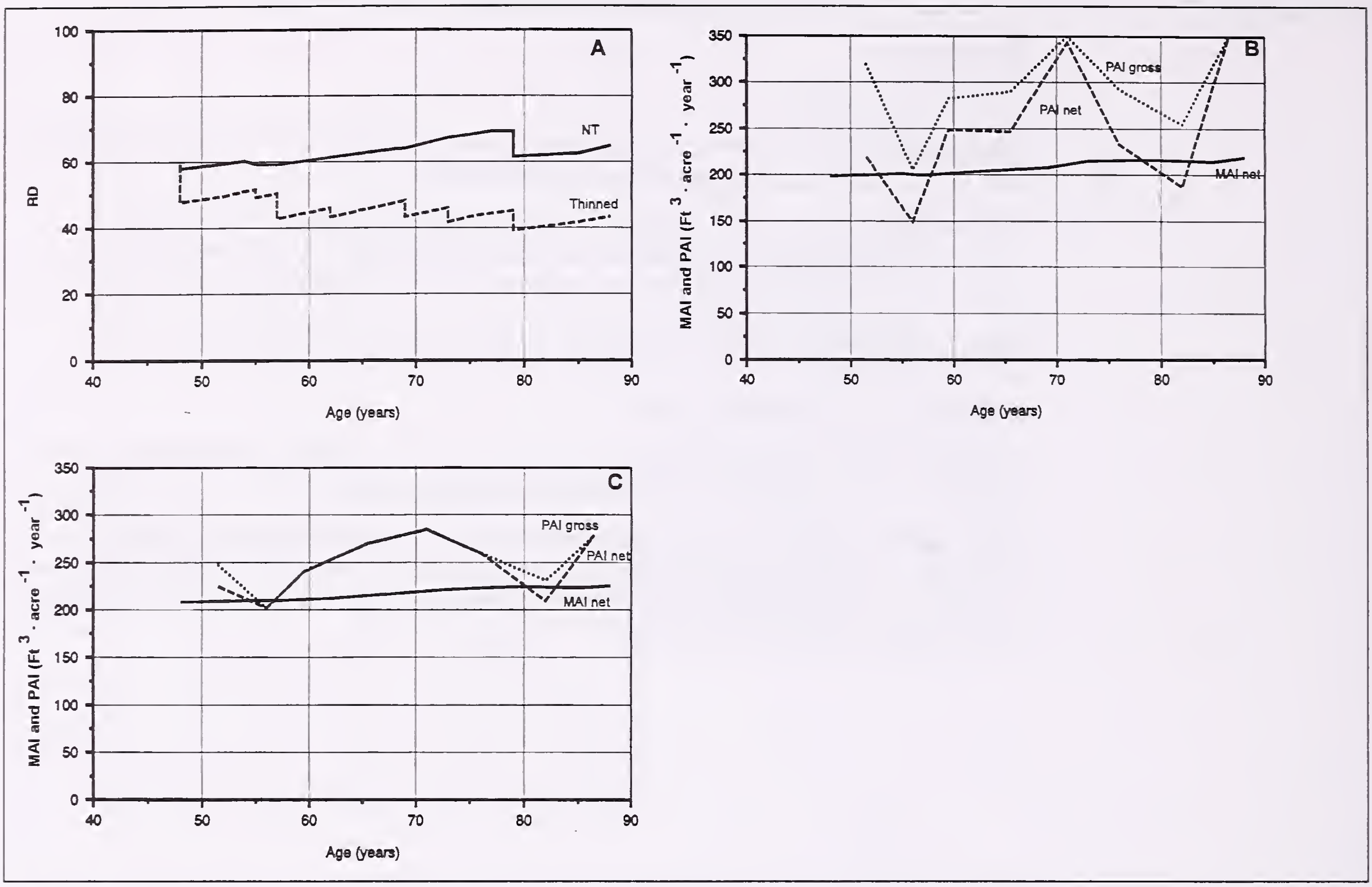

Figure 6—Port Blakely XT-2 (A) relative density (RD) trends for thinned and unthinned treatments; and MAI and PAI trends for (B) unthinned and (C) thinned treatments.

Port Blakely XT-2

Location—T.18N., R.5W. (southwest Washington, near McCleary) .

Site class—I.

Stand origin—Natural.

Design—Two contiguous 10-acre treatment areas, one thinned and one unthinned. Each sampled by five systematically located 1/5-acre plots.

Treatments—Thinned vs. unthinned.

History—Established in 1948 at age 49. Remeasured and thinned at frequent intervals until final measurement and cut in 1988, age 89. A salvage cut was made on the "control" in 1979.

Published documentation—None.

Results—Removals were frequent and light in the thinned stand, and resulted in a gradual reduction to around RD40-45 in the later years (fig. 6). The control built up to the approximately "normal" value of RD69 prior to the 1979 cut. MAI and PAI values indicate that culmination in net volume had not been reached at age 88, and the MAI and PAI curves were nearly parallel. PAIgross was still well above MAI on the control.

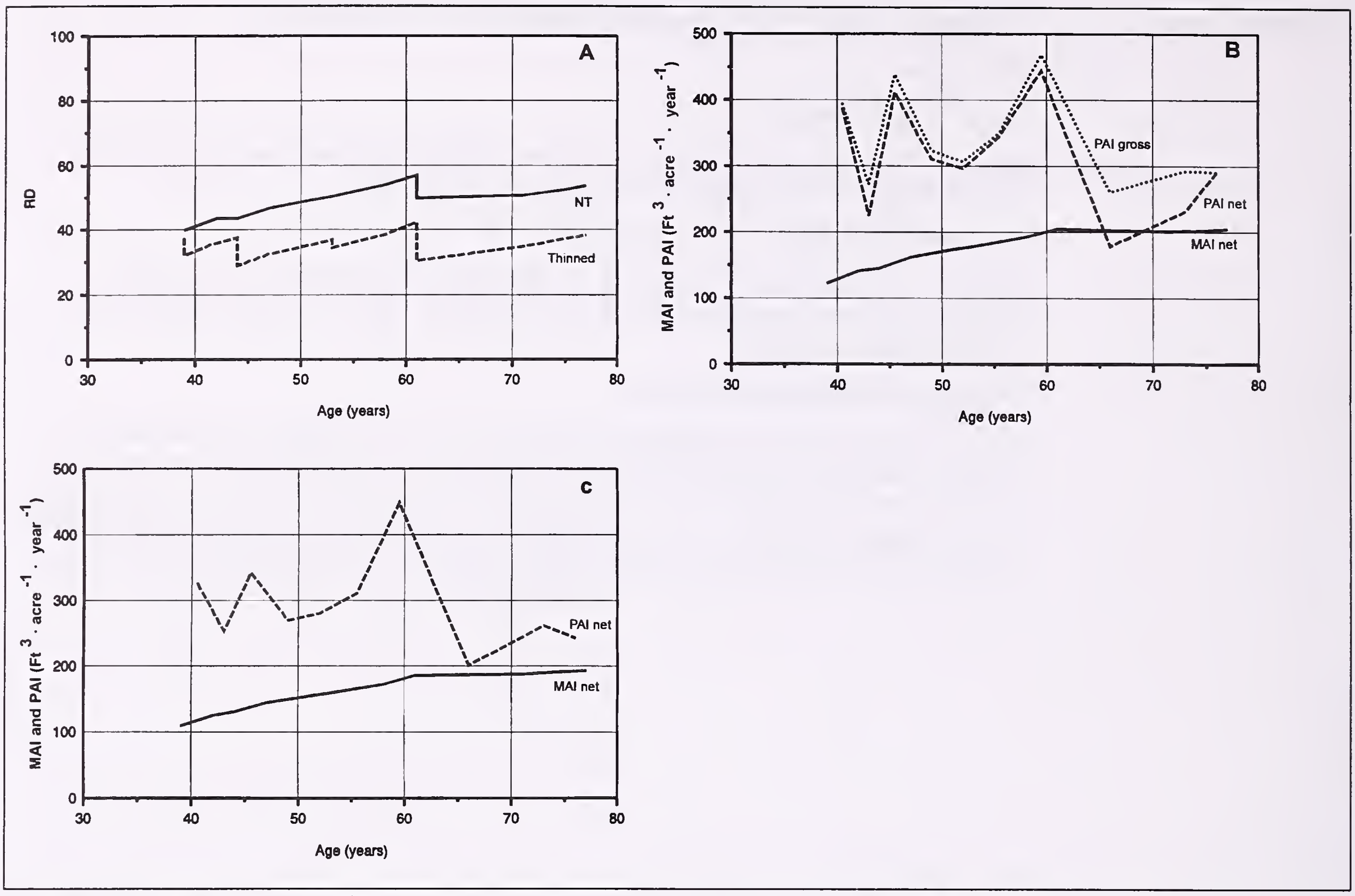

Figure 7—Port Blakely XT-3: (A) relative density (RD) trends for thinned and unthinned treatments; and MAI and PAI trends for (B) unthinned and (C) thinned treatments.

Port Blakely XT-3

Location—T.18N., R.5W. (southwest Washington, near Elma) .

Site class—I–.

Stand origin—Natural.

Design—Two adjacent 10-acre treatment areas, one thinned and one unthinned. Each sampled by four systematically located 1/5-acre plots.

Treatments—Thinned vs. unthinned. The "unthinned control" plot was not in fact untreated; a cut was made in 1975 at age 61, probably salvage.

History—Established in 1953 at age 39. Remeasured at frequent intervals, most recently in 1991 at age 77. Initial stocking apparently quite open, as evidenced by presence of only 147 stems per acre at establishment.

Published documentation—None.

Results—RD trends (fig. 7) show that the "control" is still of quite moderate density, reflecting both the 1975 cut and low initial density. Mortality was not recorded in the thinned stand, and was presumably salvaged and included in the cut. Although culmination in MAInet has not occurred by age 77, it seems probable in the near future.

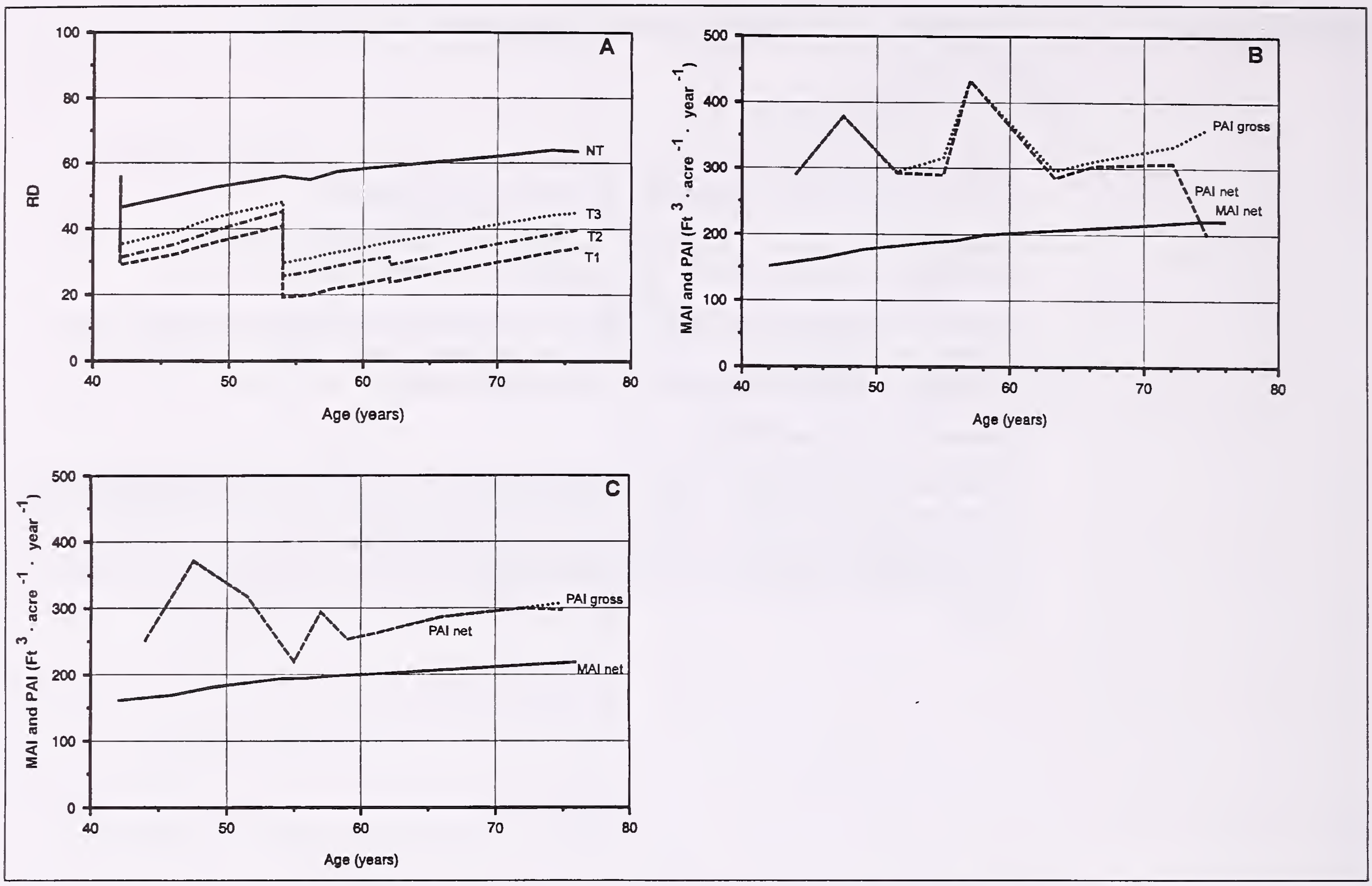

Figure 8—Port Blakely XT-7: (A) relative density (RD) trends for three thinning treatments and control; and MAI and PAI for (B) unthinned, and (C) means of thinning treatments 1, 2, and 3.

Port Blakely XT-7

Location—T.18N., R.5W. (southwest Washington, near Elma).

Site class—II+.

Stand origin—Natural.

Design—Four contiguous 8-acre treatment areas, each sampled by eight systematically distributed 1/10-acre plots.

Treatments—Three levels of thinning plus unthinned control.

History—Established in 1958 at age 42. Two relatively heavy thinnings were made, at ages 42 and 54. A few additional trees were cut at age 62. Last remeasured in 1991 at age 76. The stand was apparently quite open at establishment, as evidenced by the relatively low initial number of stems and negligible mortality in the control until quite recently.

Published documentation—None.

Results—RD trends (fig. 8) show that thinning reduced the stands to low to extremely low relative density levels. They have not yet built up to anything close to levels where suppression-related mortality is anticipated. The control has only recently entered the zone of suppression related mortality.

PAIgross is far above MAI on the control; the sharp decline in PAInet on the control represents the onset of mortality, which is only now becoming important with increasing density.

MAI and PAI trends are similar for all thinned stands. There is no indication of culmination and current PAI is considerably higher than MAI and apparently increasing at age 76.

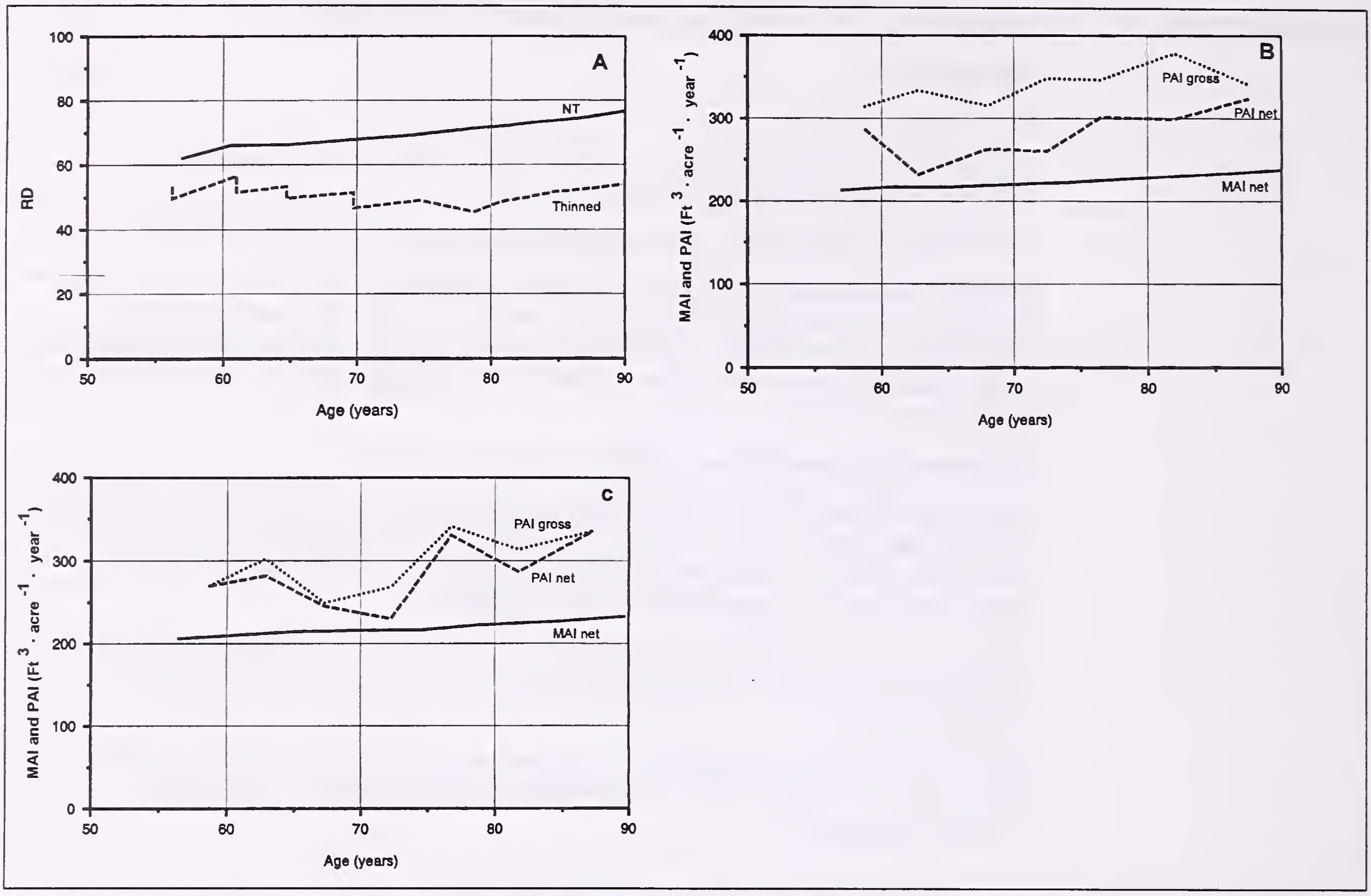

Figure 9—McCleary: (A) mean relative density (RD) trends for four Miller unthinned and four thinned plots measured to age 90, and mean MAI and PAI trends for (B) four Miller unthinned plots, and (C) four Miller thinned plots.

McCleary

Location—T.18N., R.5W. (southwest Washington, near McCleary).

Site class—I– to II+.

Stand origin—Natural.

Design—Two unthinned subareas totaling 30 acres and five thinned subareas totaling 90 acres. Sampled by systematically distributed 1/5-acre plots.

Treatments—One thinning treatment vs. unthinned. Each subarea within the thinned area received four thinnings at intervals of 5 years, one area being thinned each year. Initial thinning had a d/D ratio of 1.1, subsequent thinnings 0.80-0.85.

History—Established in 1949 at age 56. Original study discontinued in 1972 at age 78. A fertilization study was then superimposed on a subset of the plots (Miller and Webster 1979), including four unthinned unfertilized and four thinned unfertilized plots; measurements on these were continued until 1983 (age 90).

Published documentation—Reukema and Pienaar (1973).

Results—Stocking retained on the thinned area was relatively high and nearly constant (fig. 9). Density was reduced below the zone of competition related mortality, but little more. After the first thinning, subsequent thinning was from below.

MAI was still increasing on the four unthinned and four thinned plots of the Miller subset through age 90. PAI of both unthinned and thinned plots has been increasing.

MAI and PAI trends in the original experiment, calculated as means of all plots in each treatment, show roughly constant though erratic PAInet and increasing PAIgross toward the end of the period of observation. PAI trends are similar in shape to those in the Miller plots for the same time period, but at a lower level. PAInet and MAInet curves crossed at around age 70, but PAInet increased in the subsequent period and one cannot say that culmination was reached.

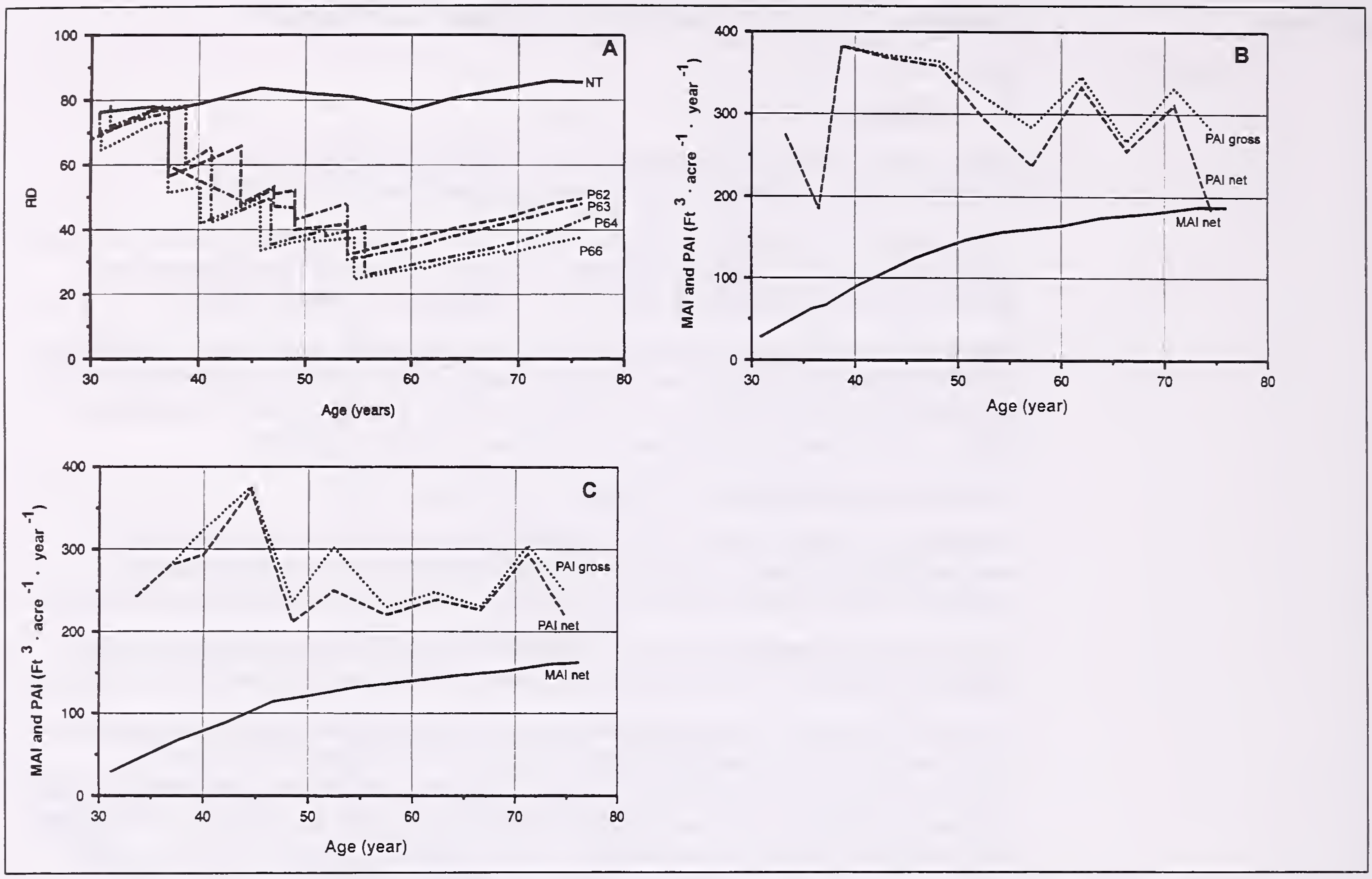

Figure 10—Schenstrom: (A) relative density (RD) trends, and MAI and PAI trends for (B) unthinned plot 283, and (C) means of thinned plots 62, 63, 64, and 66.

Schenstrom

Location—Cowichan Lake, Vancouver Island, BC.

Site class—II–.

Stand origin—Natural.

Design—Five plots ranging from 0.4 to 1.0 acre. Initial individual tree measurements were on very small plots and were expanded to present basis in 1940. Four thinned plots, one control.

Treatments—Original intent (Warrack 1979) was to include one plot for each combination of crown vs. low thinning and heavy vs. light thinning. In actuality there was little consistency in thinning treatments in the later years.

History—Established at age 18 in winter 1929-30. Initial thinning in 1929 should be considered a light precommercial thinning (PCT). Subsequent thinnings, from 1940 on, were frequent and very light after 1964.

Published documentation—Warrack (1967, 1979).

Results—Although individual thinnings were relatively light, collectively they reduced the thinned plots to quite low levels of stocking (RD25-32 according to treatment) by 1964 (fig. 10). At the most recent available measurement (1986), the plots were still only about half the relative density of the control. Volume production on the control has been higher than on any of the thinned plots, but thinned plot diameters are much larger.

PAInet on the unthinned plot seems to be slowly declining; PAInet intersects the MAInet curve at age 76 because of mortality in the last growth period, which may or may not indicate culmination. The thinned plots have not culminated by age 76, and the PAI trend has been nearly horizontal since age 48.

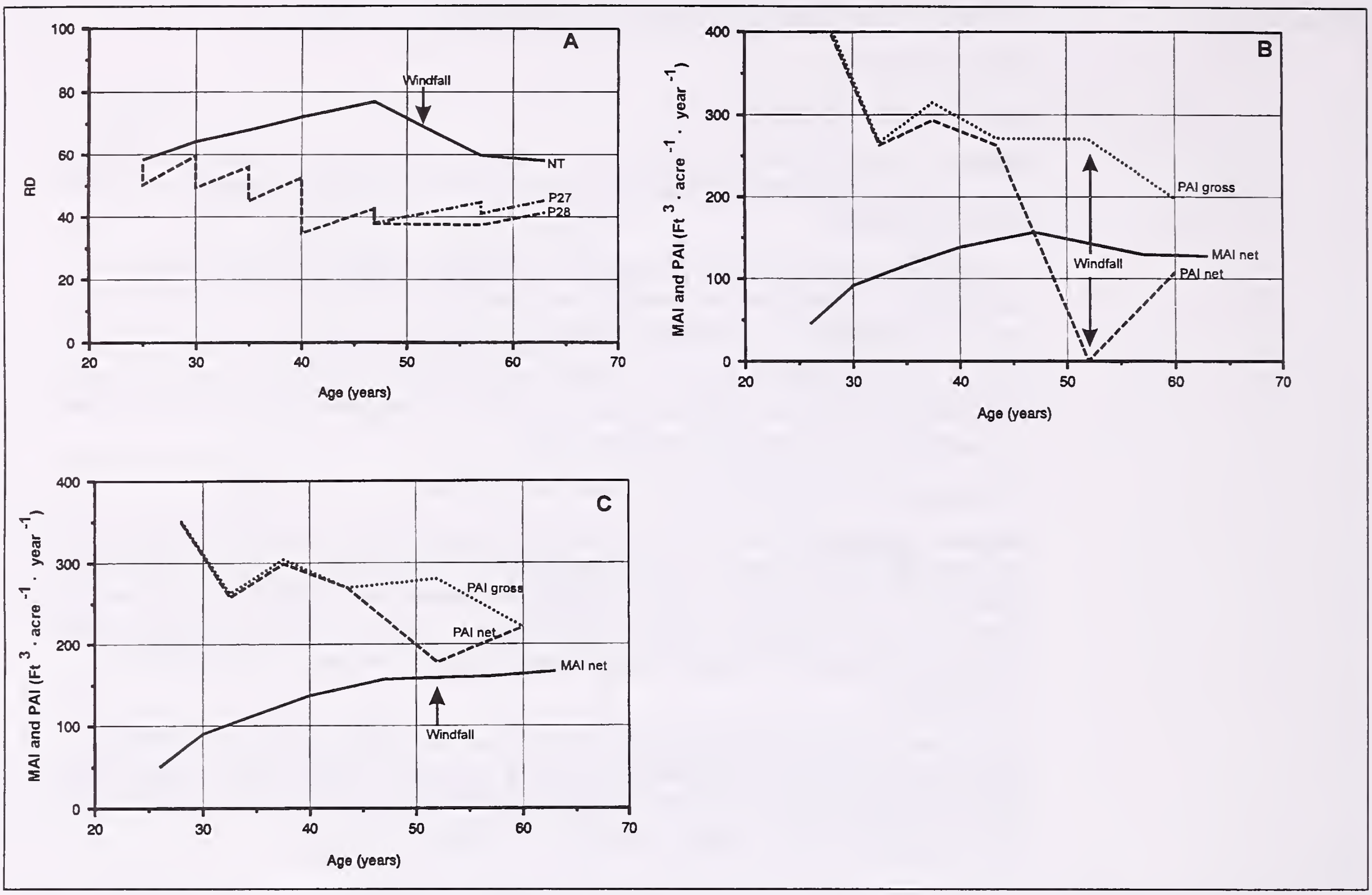

Figure 11—Snow Creek: (A) relative density (RD) trends of unthinned plot 28 and thinned plots 26 and 27; and MAI and PAI trends on (B) unthinned plot 28 and (C) means of thinned plots 26 and 27. Abruptly reduced RD at age 56 and reduced PAI in the period 1972-82 reflect windfall.

Snow Creek

Location—T.28N., R.2W. Olympic National Forest (near Quilcene, WA).

Site class—II- to III+.

Stand origin—Planted.

Design—Three nearby 0.5-acre plots.

Treatments—Two thinned plots treated alike, one unthinned plot.

History—Plots established in spring 1951 within a 1927 plantation. Thinnings were light and frequent, corresponding to then current ideas of 10 feet of height growth as a suitable thinning interval. Severe windfall damage and salvage occurred on the unthinned plot in 1979, with lesser but considerable damage on the thinned plots. Most recent measurement in 1988 at age 64 from seed.

Published documentation—Worthington (1961).

Results—The abrupt drop in RD on the unthinned plot and moderate reduction on thinned plots (fig. 11) were caused by the 1979 windfall and subsequent salvage. Sharp declines in MAInet, PAInet, and PAIgross for the unthinned plot and the two thinned plots are likewise associated with 1979 windfall and salvage. It is unclear whether this is permanent or a temporary decline that will be followed by recovery.

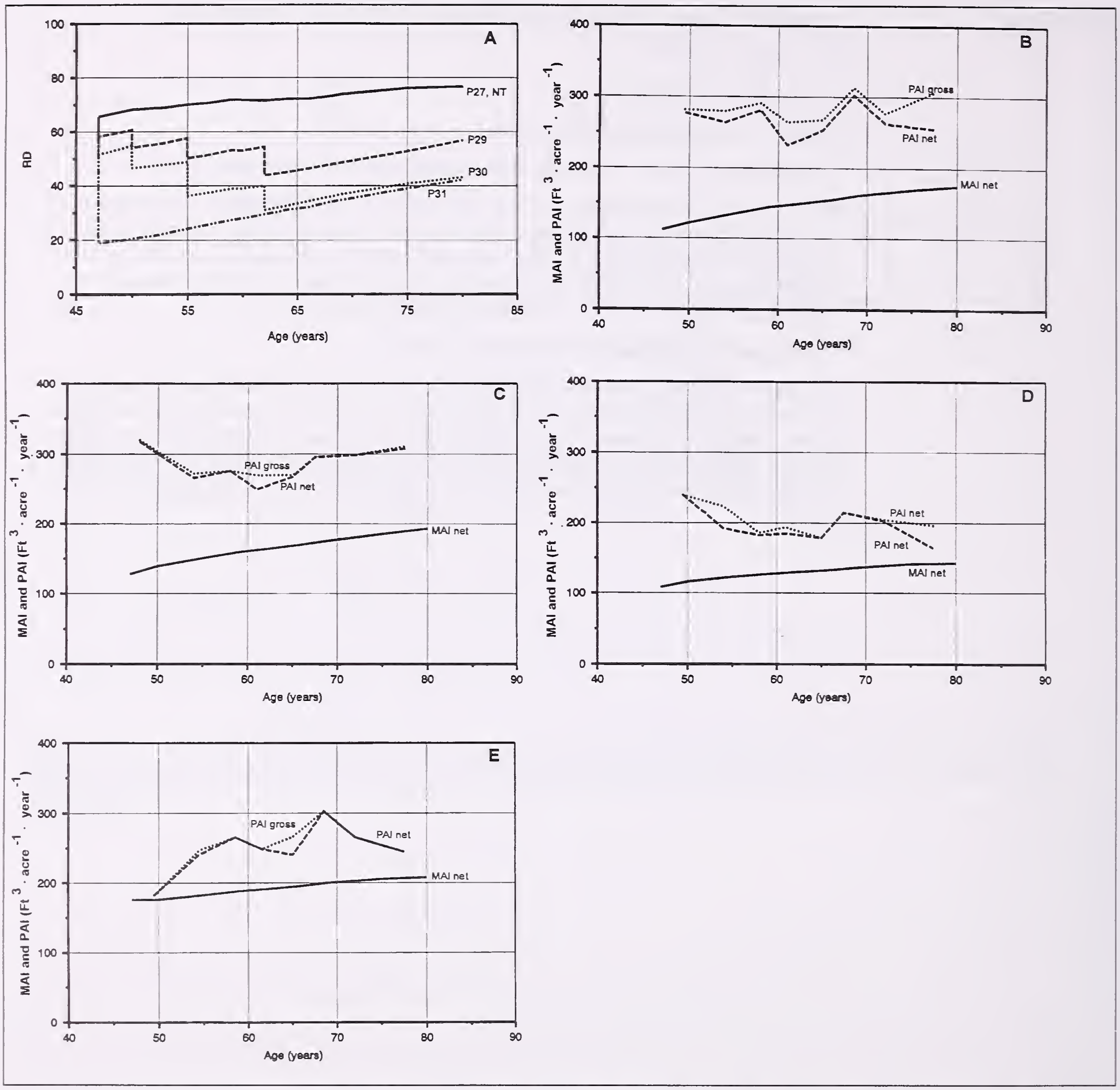

Figure 12—Black Rock: (A) relative density (RD) trends for plots 27, 29, 30, and 31, and MAI and PAI trends for (B) plot 27, unthinned; (C) plot 29, light thinning; (D) plot 30, heavy thinning; and (E) plot 31, very heavy thinning.

Black Rock

Location—T.10S., R.7W. (Oregon Coast Range, near Fall City) .

Site class—II to III.

Stand origin—Natural.

Design—Individual large plots. Some but not all treatments replicated.

Treatments—A variety of different thinning treatments and schedules. Treatments for those few plots included in these comparisons were plot 27, no thinning; plot 29, light thinning; plot 30, heavy thinning; and plot 31, heavy crop tree thinning. There are considerable differences in site index among these nearby plots; estimated site indexes for plots 27, 29, 30, and 31 are 112, 122, 106, and 134, respectively.

History—Established in the 1950s by the late Alan B. Berg of Oregon State University (OSU). After several thinnings on some plots, thinning was discontinued in the early 1970s. This is one of the most comprehensive and potentially valuable long-term thinning experiments existing in the region. An effort is currently underway at OSU to remeasure, organize, and update the entire data set and prepare a comprehensive summary publication. Most of the data were not yet in condition for use in these comparisons, however, and the results presented here are limited to four adjacent plots, often shown to visitors, for which data are now available.

Published documentation—None.

Results—Trends for the four plots discussed are shown in figure 12. MAI is still increasing on all plots. PAI has been more or less constant over time on all four plots and is still well above MAI.

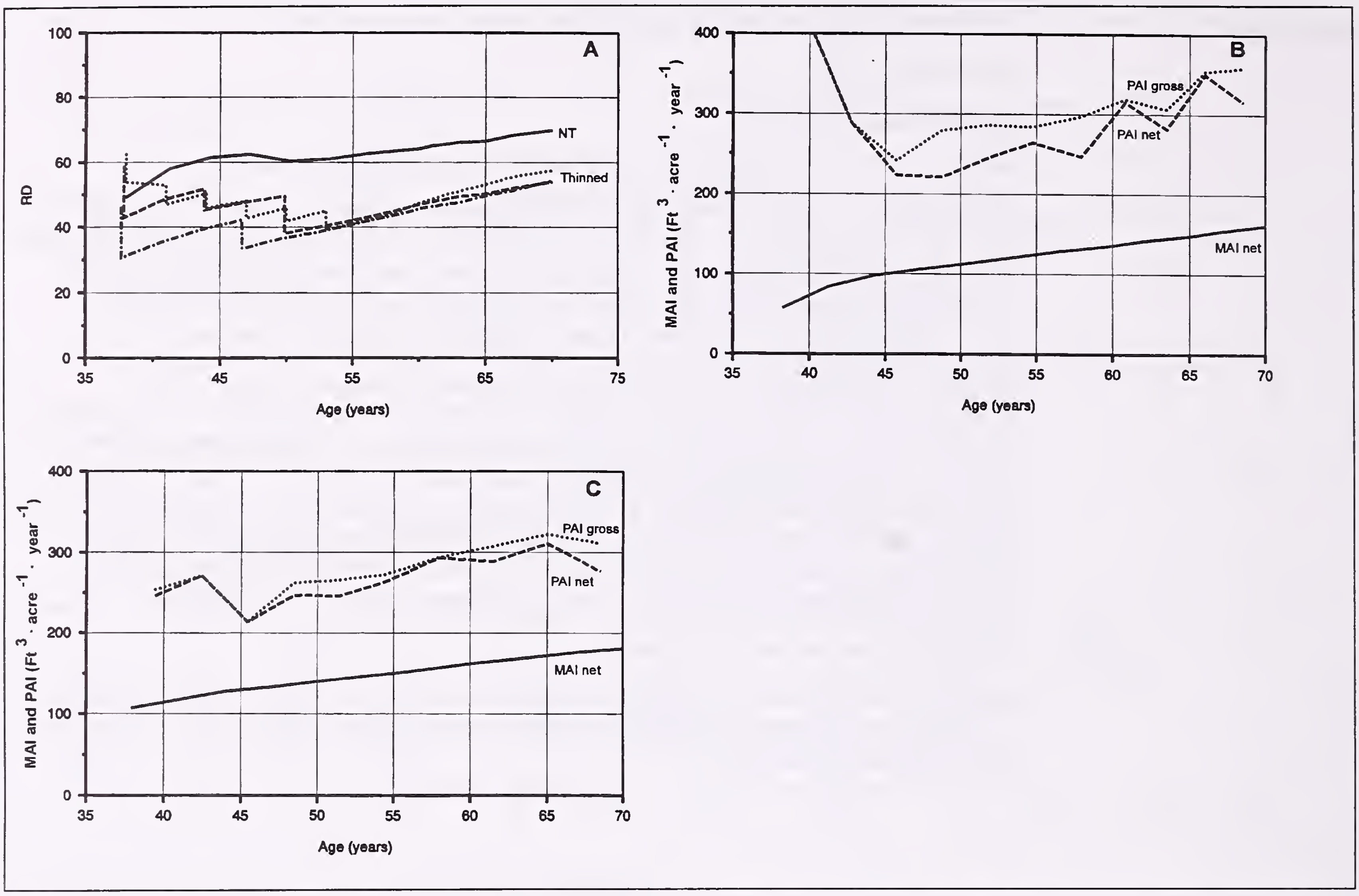

Figure 13—Voight Creek: (A) mean relative density (RD) trends of four unthinned and 14 thinned Miller plots measured to age 70; and mean MAI and PAI trends for (B) four Miller unthinned plots to age 70 ; and (C) 14 Miller plots to age 70.

Voight Creek

Location—T.18N., R.6E. (western Washington, near Orting).

Site class—Originally classified (Reukema 1972) as III by McArdle and others (1961); here reclassified as low site II according to King (1966)

Stand origin—Natural.

Design—Randomized block with three replicates of three thinning treatments plus control, comprising a total of 220 acres. Each replicate of each treatment was sampled with five 1/5-acre plots, systematically distributed (a few were later dropped because of species composition or root rot).

Treatments—Three-year, six-year, and nine-year thinning cycles and unthinned.

History—Study established in 1947. First thinning made in 1949 at an average age of 38 years. Treatments and associated measurements were staggered over time, on a 3-year remeasurement schedule. Observations on the original study extended from about age 38 to about age 60, for a total of two 9-year-, three 6-year-, and six 3-year thinning cycles. A fertilizer study was then superimposed on a subset of these plots (Miller and Webster 1979, Miller and others 1979), on which measurements were continued to age 70 on 14 thinned-unfertilized and 4 unthinned-unfertilized plots.

Severe freeze damage occurred in 1955 (age 44), with further damage by wind and snowbreakage in 1958 and 1960 (ages 47 and 49).

Published documentation—Reukema (1972).

Results—Figure 13 shows trends for the unthinned plots and 3-year-, 6-year-, and 9-year thinning cycle plots included in Miller's study. The unthinned plots had an initial average RD of about 60 and seem to approach a value of about RD70, consistent with approximate full stocking (Curtis and others 1981, McArdle and others 1961). Among thinning treatments, the shorter thinning cycles gave a more gradual reduction in density, but average RD's were about the same (40-45) for all treatments at the time of the last thinning. Thereafter they rose steadily, reaching about RD60 by age 70.

In the unthinned stand, PAI was still much above MAI to the end of the experiment; the stand was not close to culmination at age 60 (all plots) or 70 (Miller plots). The very high PAI in the initial period for the four Miller unthinned plots is associated with a change in plot size and design at measurement no. 2 and is probably not real; the very small plots used in the initial measurement cannot be expected to give good estimates for a four plot sample. Otherwise, trends for the Miller plots to age 60 correspond closely with those for all plots.

The thinned plots (both all plots and the 14 Miller plots) likewise show no evidence that the stands are close to culmination. PAI has actually been increasing through age 70.

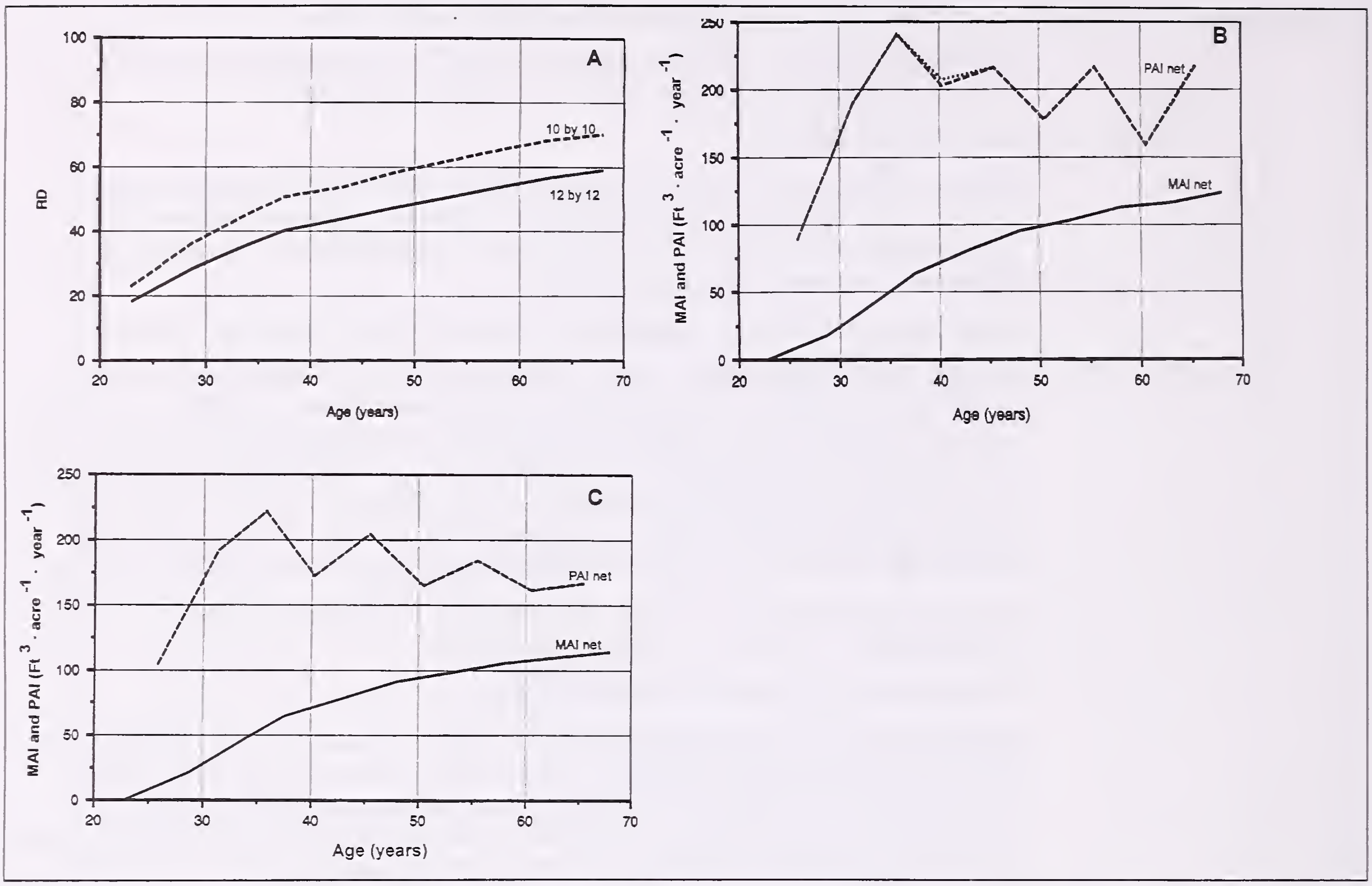

Figure 14—Wind River spacing test: (A) relative density (RD) trends for 10- by 10- and 12- by 12-foot spacings, and MAI and PAI trends for (B) 10- by 10- foot spacing, and (C) 12- by 12-foot spacing.

Wind River Spacing Test

Location—T.5N., R.7E. (Wind River Experimental Forest, near Carson, WA) .

Site class—III (wide spacings) to V (close spacings). There is a strong relation between spacing and estimated site index.

Stand origin—Planted in 1925.

Design—Contiguous areas planted to different spacings and sampled by three smaller plots of 0.25 acre at most spacings, except one 0.4-acre plot for the widest spacing. Not randomized.

Treatments—Initial spacings of 4 by 4, 5 by 5, 6 by 6, 8 by 8, 10 by 10, and 12 by 12 feet.

History—This is not a thinning study but is of interest as the oldest plantation spacing test in the Pacific Northwest. Planted in 1925 with 1+1 stock. Plots established in 1945 at age 23. Remeasured at about 5-year intervals through 1990 (age 68).

Published documentation—Reukema (1979) and earlier papers cited therein.

Results—None of the spacings are near culmination in merchantable cubic volume (although the closest spacings have reached culmination in total stem volume). Only the 10 by 10 and 12 by 12 spacings correspond to current ideas of reasonable spacings. RD, MAI, and PAI trends over time for these spacings are shown in figure 14. In these, PAI is declining only slowly and is still well above MAI. To date mortality has been negligible at these spacings though severe at the closer spacings (not shown).

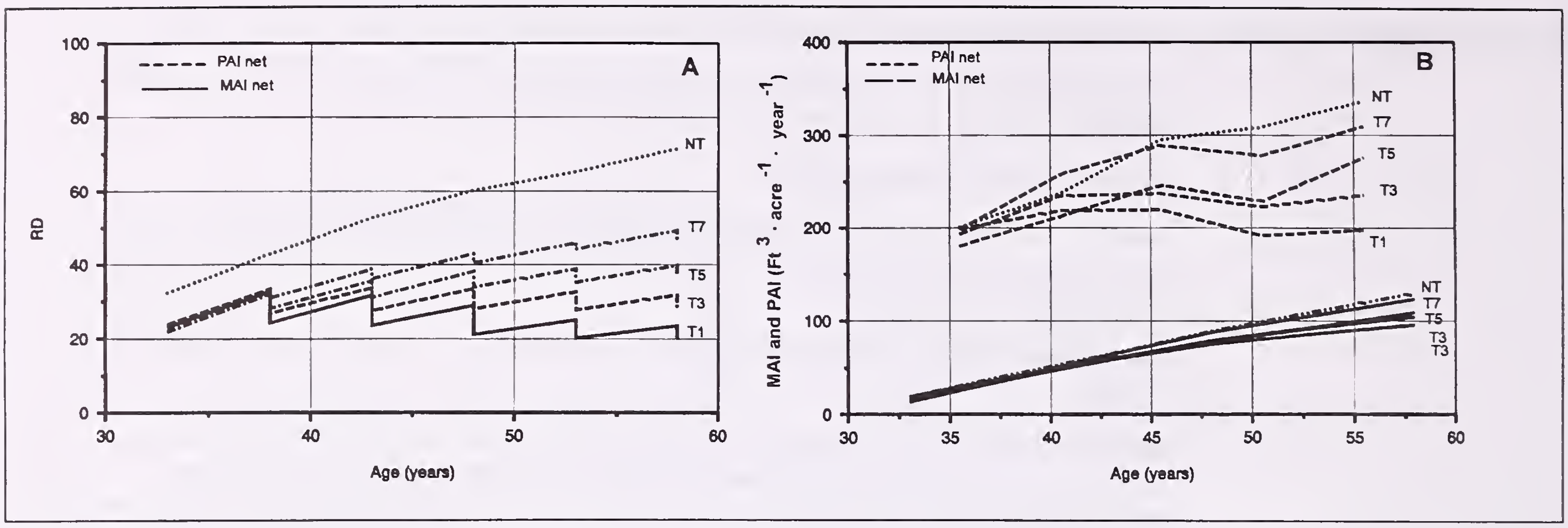

Figure 15—Stampede Creek LOGS: (A) relative density (RD) trends for thinning treatments 1, 3, 5, and 7 and unthinned control; and (B) MAInet and PAInet trends for thinning treatments 1, 3, 5, and 7 and control.

Stampede Creek LOGS

Location—T.31S., R.1W. (Umpqua National Forest, near Tiller, OR) .

Site class—III.

Stand origin—Natural.

Design—Standard levels-of-growing-stock (LOGS) cooperative study design. Twenty-seven 1/5-acre plots, three replicates of eight thinning treatments and unthinned control.

Treatments—Eight standard LOGS thinning treatments, defined in terms of observed gross basal area growth on control. Only treatments 1, 3, 5, and 7 (10, 30, 50, and 70 percent, respectively, of gross basal area control growth retained) and the control are shown here, as for the Hoskins LOGS study.

History— Established in 1968 at age 33. Remeasured and thinned at intervals of 10 feet of height increment. Most recent measurement in 1993 at age 58. This has not completed the full LOGS treatment sequence.

Published documentation— Curtis (1992b).

Results—Trends for treatments 1, 3, 5, and 7 and the control are shown in figure 15. Mortality has been slight and PAIgross differs little from PAInet. PAI at age 58 is roughly twice the corresponding MAI for each treatment; there is no indication of any approach to culmination.

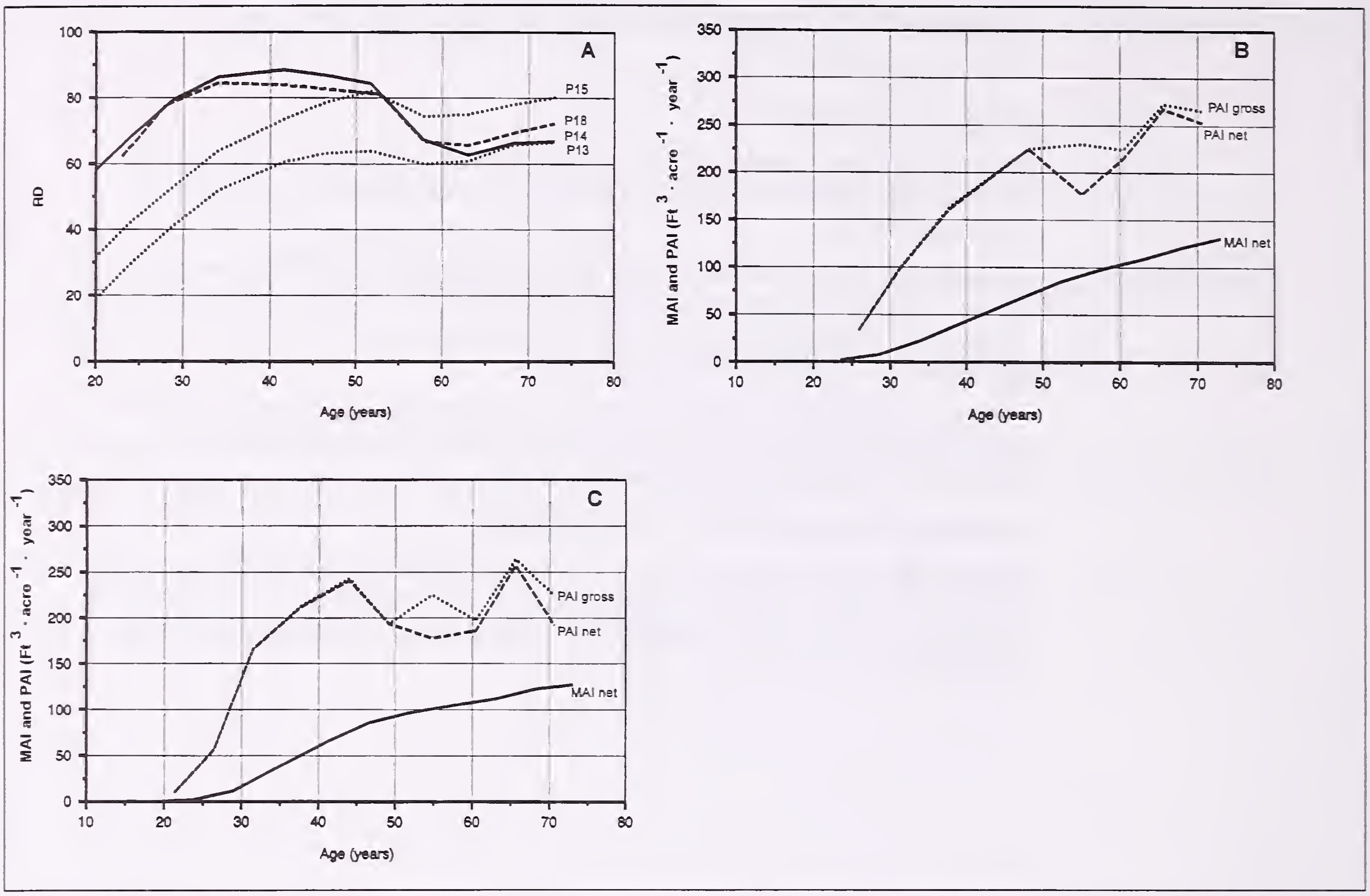

Figure 16—Martha Creek: (A) relative density (RD) trends for unthinned plots 14 and 18, plot 13 (systematic respacing) and plot 15 (selective) respacing; and corresponding mean MAI and PAI for (B) unthinned and (C) respaced plots.

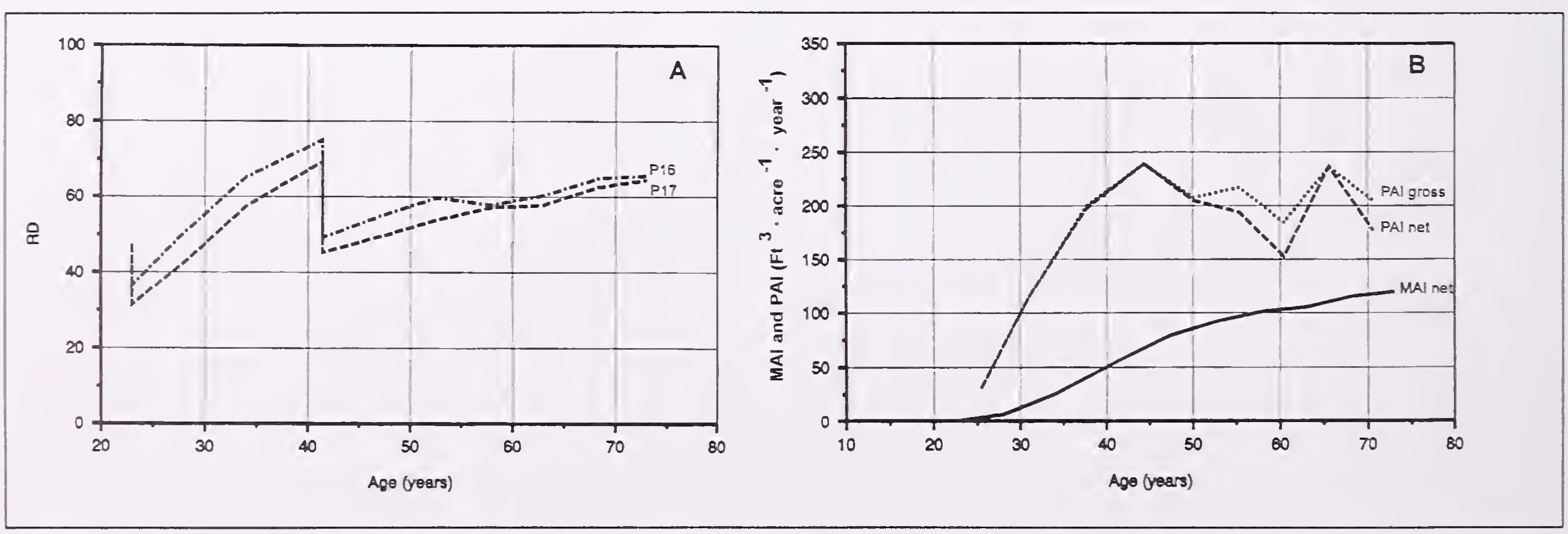

Figure 17—Martha Creek: (A) relative density (RD) trends for twice-thinned plots 16 and 17, and (B) corresponding mean MAI and PAI.

Martha Creek

Location—T.4N., R.7E., Wind River Experimental Forest (near Carson, WA).

Site class—III.

Stand origin—Natural.

Design—Six individual large plots (0.75-1.1 acre). No true replication.

Treatments—Two unthinned plots; two plots precommercially thinned to 8 by 8 feet, one selectively and one systematically; two plots precommercially thinned followed by a second thinning.

History—Naturally seeded following logging and slash burn. Most trees originated in 1911. One unthinned plot (14) and the two 8 by 8 spacing plots (13 and 15) were established in 1920, although complete tagged tree records date from 1929. One unthinned plot (18) and the two twice-thinned plots (16 and 17) were established in 1933. After a first thinning at establishment, plots 16 and 17 were lightly thinned again in 1952. Plots 13 and 15, in particular, had heavy mortality (snowbreakage) in the period 1962-68 (ages 52-58). Records extend to 1983, age 73.

Published documentation—Meyer (1931). Much additional information is contained in: Reukema, D.L. Final progress report on Wind River PSP's 13, 14, 15, 16, 17, 18 (Martha Creek flat) and 10, 11, 19, 20 (Lookout Mt. Road). 8/29/1986, rev. 9/8/1987. Unpublished report. On file at: Forestry Sciences Laboratory, Olympia, WA.

Results—RD and mean MAI and PAI trends for the two unthinned plots (14, 18) and the two 8 by 8 respaced plots (13, 15) are shown in figure 16, those for twice-thinned plots 16 and 17 in figure 17.

Although excessively dense by current standards, the stands were still growing well at the last measurement. PAI was still well above MAI; culmination had not been reached at age 73. Reduced growth in the 1962-68 period, associated with snowbreakage and mortality, was thought at the time to indicate approaching culmination. The stands have since recovered, however, and resumed vigorous growth.

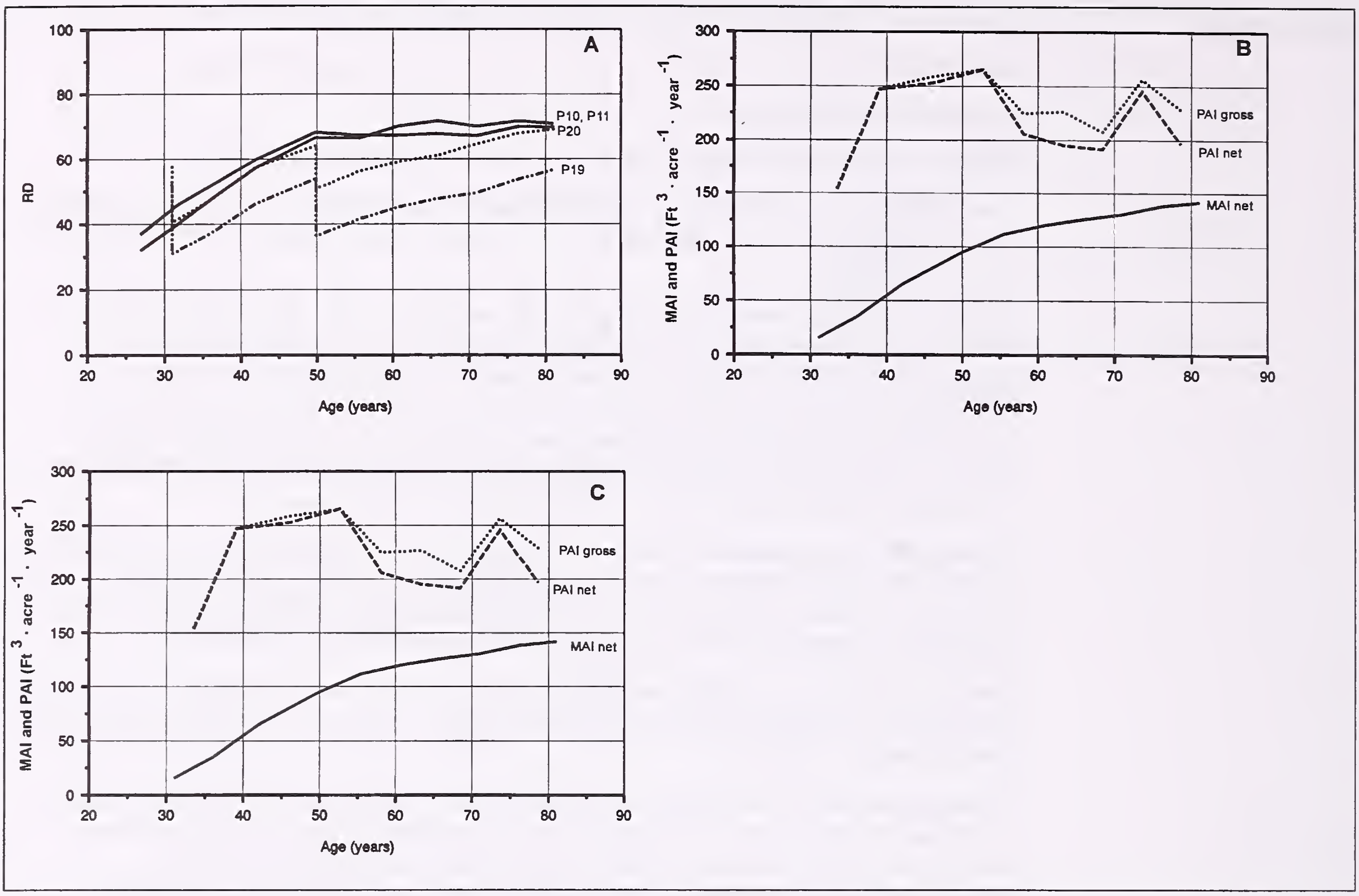

Figure 18—Lookout Mountain: (A) relative density (RD) trends for unthinned plots 10 and 11 and for thinned plots 19 and 20; and mean MAI and PAI trends for (B) unthinned plots 10 and 11, and (C) thinned plots 19 and 20.

Lookout Mountain

Location—T.4N., R.7E., Wind River Experimental Forest (near Carson, WA) .

Site class—III (plots 19 and 20) to IV+ (plots 10 and 11).

Stand origin—Natural.

Design—Individual large plots (0.75-1.1 acre).

Treatments—Two unthinned plots, and two plots receiving an initial precommercial thinning, followed by a later thinning.

History—Stand was established by natural seeding after the 1902 Yacolt fire. Two unthinned plots (10 and 11) were established in 1929. Two thinned plots (19 and 20) were established in 1933; both received a light precommercial thinning in that year followed by a second thinning in 1952. The second thinning on plot 19 was comparatively heavy, whereas that on plot 20 was very light. Record extends to 1983, age 81. Estimated site index is somewhat lower (IV+) on the two unthinned plots than on the two thinned plots (III).

Published documentation—Meyer (1931).

Results—RD, MAI, and PAI trends are shown in figure 18. Culmination had not been reached at age 81. Trends in the two unthinned stands and lightly thinned plot 20 suggest a possible approaching culmination, primarily because of increasing mortality in these dense stands; gross PAI continues at a high level. The more heavily thinned plot 19 shows no indication of approaching culmination.

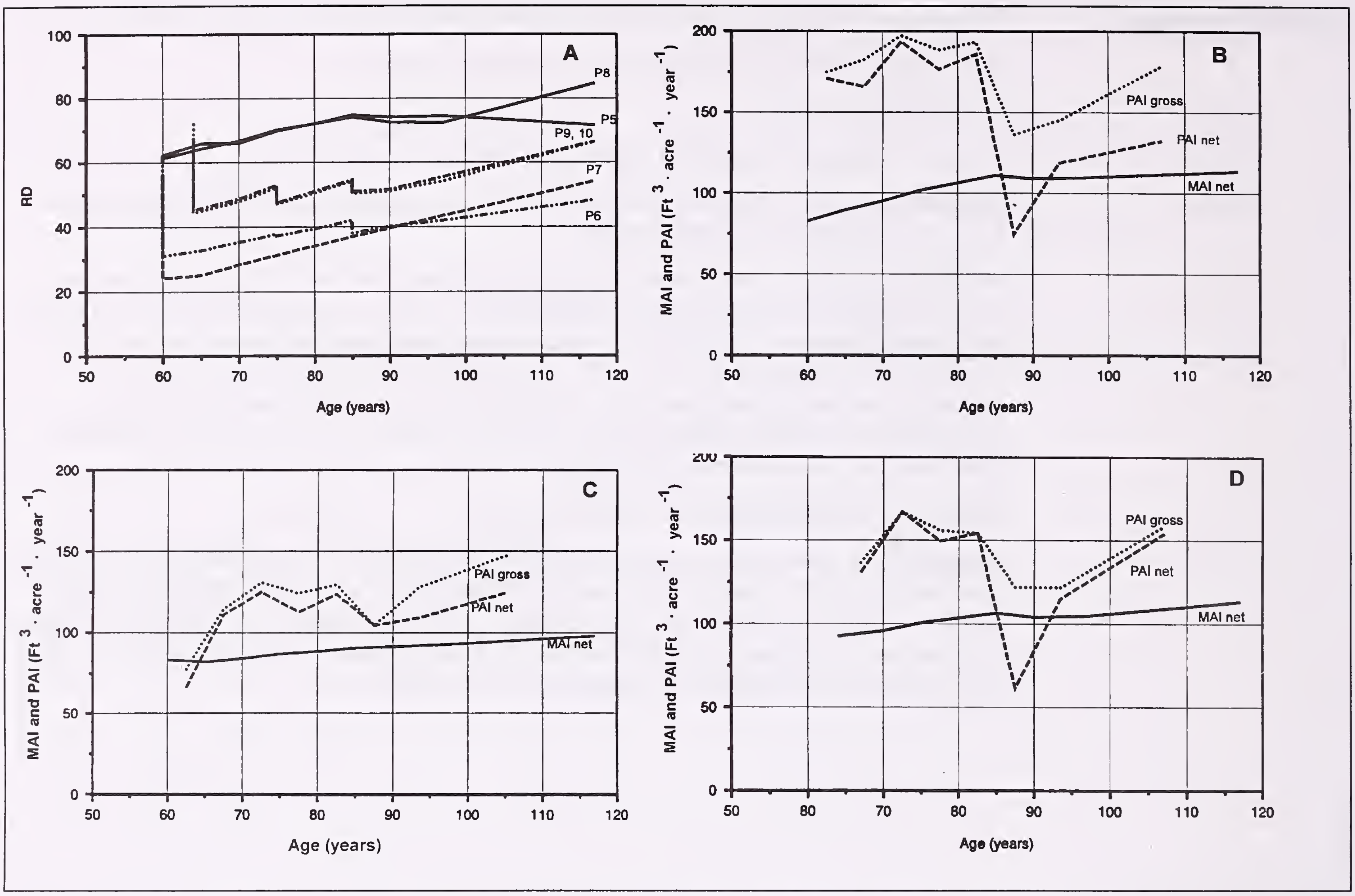

Figure 19—Mount Walker: (A) trends of relative density (RD) for two unthinned and four thinned plots; and means of MAI and PAI for (B) unthinned plots 5 and 8; (C) heavily thinned plots 6 and 7; and (D) lightly thinned plots 9 and 10.

Mount Walker

Location—T.26N., R.2W., Olympic National Forest (near Quilcene, WA).

Site class—IV+.

Stand origin—Natural.

Design—Individual large plots (0.5 to 1.0 acre), no replication.

Treatments—Two unthinned plots, four plots thinned to various degrees, removing 31 and 37 percent of basal area on plots 9 and 10 respectively; and 44 and 50 percent of basal area on plots 6 and 7, respectively.

History—Plots 5-8 were established in 1934 at age 60, and plots 9 and 10 in 1937. Thinned in year of establishment. Plots 6, 9, and 10 received additional very light cuts in 1949 and 1958. Study was terminated in 1971 but was subsequently recovered and remeasured in 1991.

Published documentation—Worthington (1966).

Results—Based on RD trends (fig. 19), the plots clearly fall into three groups; unthinned (plots 5 and 8), lightly thinned (plots 9 and 10), and heavily thinned (plots 6 and 7). With the exception of plot 5 (unthinned), which suffered considerable recent mortality, the other plots are still increasing in MAInet at age 117. All plots showed depressed growth and considerable mortality in the 1958-63 growth period, with subsequent recovery.

Curtis, Robert O. 1995. Extended rotations and culmination age of coast Douglas-fir: old studies speak to current issues. Res. Pap. PNW-RP-485. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 49 p.

Trends of mean annual increment and periodic annual increment were examined in 17 long-term thinning studies in coast Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco) in western Washington, western Oregon, and British Columbia. Maximum ages included ranged from about 90 years on high sites to 117 years on a low site. None of the stands had clearly reached culmination of mean annual increment, although some appeared close; periodic annual increments declined only slowly. Extended rotations combined with increased thinning harvests are promising components of any strategy to reduce conflicts between timber production and other forest values. These comparisons indicate that rotations can be considerably extended without reducing long-term timber production. A major problem in such a strategy is design of thinning regimes that can maintain some reasonable level of timber flow during any transition period.

Keywords: Growth and yield, mean annual increment, rotation, Douglas-fir, *Pseudotsuga menziesii*, alternative silviculture, ecosystem management.

Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, Oregon 97208-3890

U.S. Department of Agriculture
Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, Oregon 97208-3890